ESTIMATES OF GENETIC PARAMETERS AND CORRELATIONS FOR A STRAWBERRY BREEDING POPULATION GROWN IN A SUBTROPICAL ENVIRONMENT

By

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Para sa Daddy at Mommy,
nangarap para sa amin
para mangarap din kami.

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TABLE OF CONTENTS

page

ACKNOWLEDGMENTS iv

LIST OF TABLES vii

ABSTRACT x

CHAPTERS

1 INTRODUCTION 1

2 REVIEW OF LITERATURE 11

Morphology of the Strawberry 11
Components of High Early Yield 12
Other Factors Related to Yield 19
Firmness 21
Components of Variance and Heritability 22
Genetic Correlation and Indirect Selection 28
Nursery Selection 30

3 MATERIALS AND METHODS 33

Plant Materials 33
Experiment 1 (Cropping season 1994-1995) 33
Experiment 2 (Cropping season 1995-1996) 36

4 YIELD COMPONENT ANALYSIS 40

5 COMBINING ABILITY 53

6 ESTIMATES OF GENETIC PARAMETERS 62

Variance Components 64
Genetic Variances 67
Heritability 70

7 GENETIC PARAMETERS FROM PART AND COMPLETE RECORDS 76

8 GENETIC CORRELATION 83

9 NURSERY SELECTION 94

10 CONCLUSIONS 103

LITERATURE CITED 107

APPENDIX 113

BIOGRAPHICAL SKETCH 138

LIST OF TABLES

Table page

1-1. Range of monthly distribution of production and dollar value of fruit at different months in the cropping seasons 1989-1994 in Florida 5

2-1. Estimates of h^2 for earliness or early yield in some crops 24

2-2. Additive genetic variances for some yield components 25

2-3. Estimates of h^2 for number of fruits 25

2-4. Estimates of h^2 for fruit size 25

2-5. Estimates of h^2 for yield 27

3-1. Genotypes used as female and male parents 34

3-2. Expected mean squares for a mixed model with data taken on a plot basis (Experiment 1) 36

3-3. Expected mean squares for a mixed model with data taken on individual plants (Experiment 2) 39

4-1. Equations used to calculate R^2 in multiple regression of yield 41

4-2. Correlation coefficients among vegetative traits (1995-1996) 43

4-3. Correlation coefficients among vegetative and reproductive traits (1995-1996) 45

4-4. Correlation coefficients among reproductive traits (1995-1996) 49

5-1. Genotypes used as female and male parents 54

5-2. Mean squares for general and specific combining ability in vegetative and production traits in strawberry grown at Dover, Florida (1994-1995) 55

5-3. Mean squares for general and specific combining ability in vegetative and production traits in strawberry grown at Dover, Florida (1995-1996) 57

5-4. Percentages of sums of squares due to general (GCA) and specific combining ability (SCA) in strawberry at Dover, Florida (1994-1995) 58

5-5. Percentages of sums of squares due to general (GCA) and specific combining ability (SCA) in strawberry in Dover, Florida (1995-1996) 59

6-1. Pedigree of genotypes used as female and male parents 63

6-2. Variance components for vegetative traits, yield and fruit firmness (1994-1995) 65

6-3. Variance components for vegetative and production traits on an individual plant basis (1995-1996) 66

6-4. Genetic variances for vegetative traits, yield and fruit firmness (1994-1995) 67

6-5. Genetic variances for vegetative traits on an individual plant basis (1995-1996) 69

6-6. Heritability of vegetative traits, yield and fruit firmness (1994-1995) 71

6-7. Heritability of vegetative traits on an entry-mean (family) basis (1995-1996) 72

6-8. Heritability of vegetative traits on an individual plant basis (1995-1996) 74

7-1. Variance components for monthly and total season yield based on part-records, Dover, Florida (1995-1996) 78

7-2. Variance components for monthly and total season yield based on complete records, Dover, Florida (1995-1996) 78

7-3. Genetic variances for monthly and total season yield based on part-records, Dover, Florida (1995-1996) 80

7-4. Genetic variances for monthly and total season yield based on complete records, Dover, Florida (1995-1996) 80

7-5. Individual heritability of monthly and total season yield based on part-records, Dover, Florida (1995-1996) 81

7-6. Individual heritability of monthly and total season yield based on complete records, Dover, Florida (1995-1996) 81

8-1. Genetic correlation among vegetative traits in strawberries grown at Dover, Florida (1995-1996) 85

8-2. Genetic correlation between vegetative and reproductive traits in strawberries (Dover, Florida, 1995-1996) 87

8-3. Genetic correlation among number of inflorescences and fruit yield in strawberries grown at Dover, Florida (1995-1996) 91

8-4. Genetic correlation among monthly measures of fruit yield in strawberries grown at Dover, Florida (1995-1996) 92

9-1. Mean squares for three traits measured on selected and randomly picked seedlings from 24 families in the nursery at Dover, Florida (1995) 95

9-2. Vegetative attributes of selected and randomly picked seedlings from 24 families in the nursery at Dover, Florida (1995) 96

9-3. Results of the ANOVA for traits measured on plants from selected and randomly picked seedlings in the fruiting field at Dover, Florida (1995-1996) 97

9-4. Vegetative and reproductive attributes of plants in the fruiting field from selected and randomly picked seedlings at Dover, Florida (1995-1996) 99

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ESTIMATES OF GENETIC PARAMETERS AND CORRELATIONS FOR A STRAWBERRY BREEDING POPULATION GROWN IN A SUBTROPICAL ENVIRONMENT

By

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Field experiments were conducted in two cropping seasons from 1994-1996 at Dover, Florida. Families were generated using 5 x 6 and 6 x 4 factorials in the two seasons. Genotypes designated as females were from the University of Florida breeding program, while those designated as males were University of California cultivars.

Regression analysis showed that the number of marketable fruit and average fruit weight in January could be used to predict season marketable and total weight. Significant correlation between traits was obtained, the more important of which are the positive correlation between crown number and inflorescence number, early vigor and January yield, and later vigor and March yield.

Number and weight of marketable fruit, and total and average fruit weight in January, showed significant GCA effects in both seasons. In 1995-1996, almost all traits evaluated showed significant GCA effects. Most traits had higher female + male percentage of the sum of squares due to GCA rather than to SCA effects.

Estimates of variance components, genetic variances, and family and individual narrow sense heritability for early yield, fruit size, and firmness were higher for the female population than for the male population, indicating that the female population has more variability for these traits.

Estimates of genetic parameters using part-records (every other week) were lower than estimates from complete records. In spite of the lower estimates, the heritabilities for January and March yield show the same relationship relative to each other as in complete records.

Genetic correlation trends followed phenotypic correlation trends. The more important correlations are vigor with number of inflorescences and number and weight of marketable fruit; number of inflorescences 79 DAP with early yield; and number of fruit with marketable fruit weight in the same month and for the season.

In a related study, genotypes selected in the nursery based on crown size and plant vigor had more fruit and higher fruit weight in January, February, and for the season than genotypes picked at random from the nursery.

CHAPTER 1
INTRODUCTION

The strawberry industry in the United States has been steadily expanding. Total annual acreage fluctuated between 46,080 acres and 51,330 acres in the past decade, but production rose more than 30% from 559,000 in 1987 to 814,000 tons in 1996. In the 1994-1995 cropping season, over 76,000 tons or 14.7% of the country's total fresh market production came from Florida (National Agricultural Statistics Service, 1997). This fruit was produced on only 6,000 acres (Floyd, 1996), or 12.4% of the total area harvested in the United States. Florida is first in winter fresh fruit production among the strawberry producing states, and second only to California in annual fresh fruit production (National Agricultural Statistics Service, 1997).

Strawberry is second only to citrus as the most important fruit crop in Florida in terms of dollars generated (Shermyen, 1990 and Floyd, 1996). The substantial contribution of the crop is readily apparent when viewed in terms of the proportion of its value to the value of all crops produced in the state. The acreage of strawberries planted and harvested in the state in 1994-1995 was only 6,000 acres, or 1.7 % of the total area for all crops, but the fruit was valued at $118,608,000, or 8% of the total value of all crops (Floyd, 1996).

Strawberry production in Florida has become important for two reasons. First, west central Florida, where the bulk of the state's production occurs, is an area that generally has fall and winter temperatures that are conducive to a long fruiting period (Chandler et al., 1988). Secondly, fresh strawberries in December, January, and February command high prices, thus enabling growers to get good returns on production. The lowest value per 12-pound flat in Florida in December ($9.24) was higher than the highest value per flat in March ($7.08) during the 1989-1994 cropping seasons (Florida Agricultural Statistics, 1995).

Despite the fact that west central Florida has desirable conditions for strawberry production, there has been a lack of cultivars developed specifically for this region. Yield and fruit quality of strawberries are greatly affected by the environment to the extent that one cultivar may perform well in one area, but be mediocre in another (Janick and Moore, 1996). An example is 'Selva', a California cultivar that has been relatively low yielding in Florida (Chandler et al., 1989a). Given the specific nature of strawberry cultivars, it is clear that breeding and selection should ideally be conducted in the area in which the new cultivars are to be grown.

The University of Florida strawberry breeding program is quite young, having started just 50 years ago. A history of the program from 1948 to 1997 was recorded by Chandler et al. (1988) and Galleta (1997). Albert N. Brooks, a plant pathologist at a Florida Agricultural Experiment Station near Plant City, is credited with initiating the program in 1948. In 1952, Brooks introduced 'Florida Ninety', which was selected from seedlings derived from seed of open-pollinated 'Missionary'. 'Florida Ninety' was replaced in the mid-1960s by 'Dabreak', a cultivar from Louisiana that was susceptible to

Colletotrichum diseases but had better shipping ability than 'Florida Ninety'. 'Dabreak' and other cultivars grown in central Florida were soon replaced by new cultivars from California.

From 1968-1987, the program was directed by Charles M. Howard, a plant pathologist at the Agricultural Research and Education Center near Dover. Together with Earl E. Albregts, Howard introduced 'Florida Belle' in 1975, and 'Dover' in 1979. These two cultivars are resistant to *Colletotrichum* diseases, but fruit quality problems hampered their widespread acceptance by growers.

Craig K. Chandler came to the breeding program in 1987, and starting with selections made by Howard, released 'Sweet Charlie' in 1992 and 'Rosa Linda' in 1996. Currently, breeding emphases are on desirable fruit quality, open plant architecture, desirable fruiting pattern, high productivity, and disease resistance (Galletta, 1997).

Until the release of 'Sweet Charlie' and 'Rosa Linda', most cultivars used in Florida had been developed by the University of California (UC) (Galletta, 1997). With the exception of 'Selva', which is day-neutral and starts fruiting in November, the UC cultivars are considered late fruiting. The widespread use of California cultivars may have arisen because of similarities in the California and Florida production systems. Both systems use the annual hill culture, where plants are grown on raised beds that have been fumigated and then covered with plastic mulch (Voth, 1980 and Galletta, 1997). However, the trend of planting California cultivars is changing. 'Sweet Charlie' is now planted to 38% of the Florida production area, and plantings of 'Rosa Linda' may become more widespread (Galletta, 1997).

‘Sweet Charlie’ and ‘Rosa Linda’ have higher December and January yield than ‘Oso Grande’, a California cultivar, in field trials at Dover, Florida (Chandler et al., 1997). The fruits of these two cultivars are attractive and have good flavor. ‘Sweet Charlie’ fruit is described as sweet and juicy, while ‘Rosa Linda’ fruit is full-bodied and aromatic (Chandler et al., 1997). However, these two cultivars have only moderate firmness and average fruit size. The development of new cultivars must be a continuing process. Early season fruit yield, fruit size, and firmness have been and continue to be important breeding objectives.

In Florida production, early season fruit commands higher prices, with prices falling during the season. During the period 1989-1994 in Florida, the price per flat went as high as $16.92 in December of 1993, while the highest price per flat in March was only $7.08 in 1992-1993 (Table 1-1). March is an important month because approximately one-half of the total fruit produced in Florida is picked at this time. This is also the time that large quantities of fresh fruit from California begin coming into the market causing prices to go down. The value of fresh fruit per 100 pounds from Florida in the winter was $70.60 and $72.20 in 1995 and 1996, respectively. In the spring, values of fresh fruit from California were $57.40 and $52.50 per 100 pounds in 1995 and 1996, respectively (National Agricultural Statistics Service, 1997). Since late fall and winter fruit is currently much more valuable than spring fruit, there is a strong incentive to try to shift more of Florida’s production to the late fall/winter time period.

Growers have expressed the need for cultivars with fruits that have large and uniform size. These characteristics are related to profit. Fruit size affects harvest efficiency by influencing the length of time needed to fill a container with fruit. In Italy, a one gram increase in average fruit size was found to reduce the picking costs of 1 kg of fruit by 3.5% (Malagoli and Pirazzoli, 1986 as cited in Rosati, 1993). The importance of uniformity in fruit size has also been stressed. In some cultivars, the size difference between primary, secondary, and tertiary berries is great (Sherman and Janick, 1966 and Sherman et al., 1966). Increases in the cost of picking, and the poor appearance of a crate of berries have been attributed to lack of consistency in fruit size (Johnson, 1990).

Table 1-1. Range of monthly distribution of production and dollar value of fruit at different months in the cropping seasons 1989-1994 in Florida (Florida Agricultural Statistics, 1995).

Month	Distribution of production Percentage of total	Value $/flat
December	7-15	9.24-16.92
January	9-20	9.71-11.88
February	16-29	7.08-10.92
March	40-54	5.04-7.08
April	5-13	4.84-6.59

Fruit firmness is related to the ability of fruit to maintain its quality after picking and handling. The desire for firmer fruit is evident in the cultivar choices being made by growers. In the mid-1960s for instance, growers replaced 'Florida Ninety' with 'Dabreak', a Louisiana cultivar. While susceptible to *Colletotrichum* diseases, 'Dabreak' had better shipping ability than 'Florida Ninety' (Chandler et al., 1988). More recently, the Florida industry has used some University of California cultivars that are productive, attractive, and have good shipping characteristics (Galletta, 1997). Fruit firmness is greatly affected by temperature and humidity during fruit development and ripening (Janick and Moore, 1996). The trait has also been found to be highly heritable (Hansche et al., 1968) and can therefore be improved through breeding.

With the breeding objectives of high early yield, large and uniform fruit size, and firmness in mind, the focus of my research has been on 1) identifying desirable families and parents with regard to these traits, and 2) determining the most efficient breeding method(s) by which these traits can be improved.

One way of increasing efficiency is by using the breeding method that will maximize genetic gain. Information on the extent to which a trait is affected by genes may help in choosing the best breeding method to improve that particular trait. Estimates of genetic variances, such as additive and dominance variances, and heritability help in determining the method of breeding.

The conventional methods of increasing the frequency of favorable alleles in a cross-pollinated crop are phenotypic mass selection or selection based on some type of progeny testing (Poehlman and Sleper, 1995). Modifications of these methods exist, depending on the crop, the breeding objectives, and the plant breeder, among others.

Mass selection is based on phenotype. It has been most effective when the phenotype accurately reflects the genotype and a trait can be measured easily (Poehlman and Sleper, 1995). Generally, traits amenable to improvement through mass selection should have high heritability. According to Falconer (1989), this method is usually the simplest, gives the most rapid response, and "should therefore be used unless there are good reasons for preferring another method." The efficiency of mass selection may be affected by the handling of the population. In maize, the effectiveness of the method depends on the trait being improved, the degree of isolation, and the precision of experimental techniques used (Hallauer and Miranda, 1981).

Progeny testing involves the evaluation of the offspring to give an indication of parental performance. Selection based on progeny testing is effective when traits have low heritability. Furthermore, progeny testing can give information on breeding value. A major disadvantage of this method, however, is the longer generation time that it requires (Falconer, 1989). In a comparison of three methods of parent selection in strawberries, Meulenbroek et al. (1997) found that progeny testing was useful when the horticultural value of the potential parents was already high and rapid improvement in a trait was not crucial. Otherwise, choosing parents based on their phenotypic value provided a faster and less expensive way of improving a trait when the clones used as parents in a cross differed considerably.

The two selection methods may be conducted for several consecutive years in what is referred to as recurrent selection. This involves repeated crossing and plant selection, with the object of concentrating genes for a quantitative trait while maintaining a broad genetic base (Poehlman and Sleper, 1995). Recurrent selection is useful for traits with low heritability, but is more efficient when the trait is easily recognized by the phenotype. Oil content in corn, fiber strength in cotton, and sugar content in sugar beets, have been improved using recurrent selection (Poehlman and Sleper, 1995).

The method presently used in breeding for most traits at the University of Florida-Gulf Coast Research and Education Center is recurrent mass selection. Crosses of selected parents are made in the greenhouse during the regular season. Seeds from these crosses are sown in trays, and the seedlings grown in the greenhouse until they are ready for transplanting. The hybrid seedlings are then grown in a nursery in the summer of the first year for runner plant production. Two runner or daughter plants are taken from each seedling and planted in the fruiting field in the fall. Plants are selected based on visual criteria such as vigor, plant architecture, and fruit number, size and shape. Selected plants are advanced to further trials. It takes at least six years from the time hybrid seeds are produced to the time a clone is distributed to growers as a named cultivar.

Recurrent mass selection has been successfully used in the program at the University of Florida. Several named cultivars and numbered clones with desirable traits have been developed using this breeding method. However, certain traits may be improved more efficiently using other methods.

Another way of increasing the efficiency of cultivar development is by shortening the length of time needed to develop a new cultivar. This may be accomplished in two ways. The first is through indirect selection, which requires information on genetic parameters of the population. The second approach is simply by shortening the duration of a breeding cycle.

Indirect selection is selection applied to one trait based on measurements made on a secondary trait. This kind of selection becomes effective only when the secondary trait has a higher heritability than the primary trait, and genetic correlation between the two traits is high (Falconer, 1989). The use of indirect selection is advantageous when the desired trait is difficult or expensive to measure. Indirect selection may shorten the cultivar development period if several traits that are correlated to the secondary trait may be improved simultaneously.

Part-record selection is a version of indirect selection usually applied in animal improvement programs. It is defined as "selection based on performance during a portion of the production cycle" (Shaw, 1989a). Part-record selection in both animals and perennial trees has usually been conducted to shorten the generation interval with minimal reduction of the genetic gain per generation. Shaw (1989a) states that cumulative or alternate-weeks part-record selection can be used in place of direct selection to improve yield and fruit size in strawberries. He cautions, however, that the magnitude of genetic parameters will vary depending on the traits being measured and the program design.

A second way of hastening cultivar development is by shortening the duration of a breeding cycle. This may be achieved by eliminating the first year of testing if the performance of a clone in the fruiting field can be predicted based on the phenotype of the mother plant in the nursery. In most crops, the vigor of a plant is the most important factor determining that plant's yield. In strawberries, runner or daughter plants from mother plants are the planting materials used for fruit production. It is not yet clear if the size of the mother plant will have a bearing on the yield of the runner plants when the latter are grown in the fruiting field.

Quantitative genetic studies have not been conducted on the University of Florida strawberry breeding population. Furthermore, the environment in which strawberries are grown in Florida is quite different than the environments in which most of the world's annual system production occurs. Florida's production area is considered subtropical, whereas most annual system production occurs in a Mediterranean (California, Spain, and Italy) or temperate marine environment. Benchmark information on the genetic parameters of this population is needed.

Shaw (1991) cites reports of quantitative genetic studies on strawberries conducted in Canada, Scotland, and California. There were considerable differences in the findings on inheritance of commercially important production traits in these studies. The disparity was possibly due to the differing genetic materials, test environments, and methods of evaluation. Care must therefore be exercised in choosing the quantitative methods to apply to individual breeding populations. These methods must also be appropriate for the program objectives.

This study seeks to accomplish the following specific objectives:

1. To evaluate several traits in strawberries grown in a subtropical environment and identify those important for high early yield.
2. To estimate the components of genetic variance, heritability of traits, and general and specific combining ability of different strawberry genotypes.
3. To compare estimates of genetic parameters derived from part-records with those derived from complete records.
4. To determine if genetic correlation exists among vegetative and production traits.
5. To determine if selection conducted on hybrid seedlings in the nursery will be effective in improving high early yield in the first year of fruiting field evaluation.

CHAPTER 2
REVIEW OF LITERATURE

Morphology of the Strawberry

The modern day cultivated strawberry (*Fragaria x ananassa* Duch.) arose as a result of the accidental hybridization of *Fragaria chiloensis* Duch. and *F. virginiana* Duch. Both are native New World species that were brought to Europe through different routes. *F. virginiana* was reportedly already in Europe in the late 1600s. *F. chiloensis* was brought to France in 1714 by Amedee Francois Frezier, a French army officer who obtained plants from Concepcion, Chile. Darrow (1966) gives a detailed account of the history of the cultivated strawberry.

The strawberry plant is considered a herbaceous perennial although it is grown under annual hill culture in Florida and in California. Dana (1969) describes the plant and different parts in detail. The above ground part of the plant, the crown, is a short, thick stem surrounded by leaves arranged in a rosette at close intervals. Further growth occurs through the extension of the axillary bud. A branch crown may develop in the axil of the last leaf of the main crown. Or, the bud may elongate considerably and form a runner. Daughter plants that form at the end of runners are used to multiply plants of a desirable genotype.

An inflorescence will arise only from the terminal bud of a crown. The strawberry inflorescence is a cyme. Generally, an inflorescence will have one primary flower, two secondary flowers originating from the pedicel on both sides of the primary flower, four tertiary flowers, two arising from both sides of each secondary flower, and eight quaternary flowers.

Commercial strawberries have hermaphroditic flowers, although pistillate and staminate flowers occur in some of the *Fragaria* species. The hermaphroditic flower has five white petals, five sepals, 20-35 stamens, and a variable number of pistils, depending on the position of the flower on the inflorescence. Pollen is spread by insects and presumably air currents.

The "fruit" of the strawberry is actually the enlarged, fleshy receptacle. The true fruits are the achenes that are attached to the outer part of the fruit. The size of the fruit in a cluster varies, depending on its position on the inflorescence.

Components of High Early Yield

Yield is a complex trait made up of various components. Any change in the value of these components, therefore, affects total yield.

Galletta and Himelrich (1990) devised an overall formula with eight factors that should be considered when evaluating fruit yield. These are plant fill (crown size), root capacity, bearing area, net photosynthesis, potential initiation sites (measured by the number of crowns multiplied by the number of expanded leaves on each crown minus the runners), number of flowers, realized fruit set, and average fruit size. While we are most interested in fruit yield, the formula shows that factors that affect vegetative growth may also directly affect fruit yield. In strawberries, the combination of length of the light and dark periods, the prevailing temperature and the plant's ability to tolerate hot or cold conditions, soil conditions, and disease and pest tolerance influence flowering, fruiting, and eventually yield (Janick and Moore, 1996).

In a yield component analysis of several strawberry genotypes, Strik and Proctor (1988) observed differences in productivity that suggested competition for assimilates between runners and fruits in some genotypes. Yield differences in several genotypes were due mostly to the number of berries per plant as opposed to the other measured characters. Other components that correlated with yield affected it through an indirect effect on berry number. Genotypes that showed variation in yield components but had similar yield may have reached that level through different routes.

Physiological processes that occur in the plant determine the number and size of the different organs. Olsen et al. (1985) performed a growth analysis of strawberries grown in the field, and tried to determine the pattern of dry matter partitioning and accumulation in different plant parts during the establishment and fruiting phases in a growing season. Partitioning to leaves was much less during the fruiting stages than during the plant establishment phase.

Flowering and Days to First Harvest

Flowering in strawberries is influenced by a plant's genotype and by the environment. Generally, strawberries are divided into three classes based on fruiting habit. Galletta and Himelrick (1990) and Janick and Moore (1996) describe the different classes. The "single croppers" or "June bearers" are single-cropping temperate-zone strawberries that require day lengths shorter than about 14 h or temperatures less than about 59°F for flower induction. This type is also known as "short-day" or "noneverbearing" strawberries. Most commercial cultivars are of this type. The "everbearer", "perpetual", "four seasons", "rebloomer", or "remontant" types usually fruit two or more times per cropping season in the summer or fall, and are governed by long photoperiods. Older everbearing cultivars have been classified as facultative long day plants. The day-neutral strawberries continue flowering and runnering until cold temperatures in the fall prohibit growth. Galletta and Himelrick (1990) state that all three classes have "similar flower development patterns for temperature and photoperiod", except that temperature sensitivity is greatest for the June bearers and least for the day-neutrals. In areas with mild winters such as California and Florida, June bearers are grown like everbearers (Dana, 1980, and Galletta and Himelrick, 1990).

In short day strawberries, several events take place with the lower temperatures in the fall and the accompanying shorter photoperiods. Branch crowns develop, newly formed leaves are smaller in size, flower buds form, and dormancy starts (Dana, 1980). All these events are important, but the development of branch crowns is critical because inflorescences will develop only on the terminal part of branch crowns.

The influence of genotype on flowering in strawberries is shown in the following studies. Wilson and Giamalva (1954) and Lacey (1973) evaluated the start and the duration of flowering in strawberries. Lacey (1973) took note of the date of the first and last flower, and recorded the dates of the first and last picks in seedling plants from a breeding population. Wilson and Giamalva (1954) counted the days from bloom to harvest in several strawberry varieties. They all discovered that the start and duration of flowering and fruiting varied with the genotype.

The effect of genotype is confounded by the effect of the environment. Dana (1980) describes how a change in temperature will affect a strawberry plant that has gone dormant. Dormancy in strawberries is different from the complete dormancy usually undergone by temperate-zone, woody species. A strawberry plant that has become dormant due to external conditions will resume growth when exposed to suitable growing temperatures. The growth pattern, however, will be influenced by the amount of chilling the plant has been subjected to. Minimum chilling results in poor vegetative growth and irregular flowering. Satisfaction of the cold requirement causes rapid leaf production, development of differentiated flower buds, and runner production when conditions are suitable for runner growth.

The interaction between temperature and photoperiod is one reason why the environment in which a strawberry plant grows plays such an important part in early and total yields in strawberries. This interaction is shown in the results of a study on the effects of different propagation sites on fruiting by Chandler et al. (1989b). Three strawberry clones produced ripe fruit two to three weeks earlier in Florida when the nursery stocks were propagated in Canada than when produced in Florida. Canada has considerably cooler weather during the late summer and the fall. Flower buds were probably initiated and formed earlier in stocks produced in the north.

The number of days to first harvest is a function of the number of days to flowering and from flowering to harvesting. It is well known that temperature affects growth processes, and higher temperatures will usually shorten the period to flowering. The same is true for the period between flowering and harvest. The prevailing temperature during the period from pollination and fertilization to fruit maturity affects the length of that period. High temperatures shorten this period and hasten ripening. According to Scott et al. (1980), day temperatures of 70-80°F and night temperatures of 60-65°F result in a ripening period of about 30 days. During cool weather, a variety that normally has a short fruit development period may be delayed several days. Darrow (1966 cited in Dana, 1980) gives a figure of 30 days as a "rule of thumb", but it may range from 20 days when conditions are optimal to 60 days for fall fruiting cultivars exposed to cool weather.

Number of Branch Crowns or Inflorescences

Depending on the prevailing conditions, axillary buds may remain dormant or may develop into stolons (runners) or into leafy shoots called branch crowns. Branch crowns do not have their own root system but originate from the main crown. They develop during the long days in the summer when plants usually receive adequate nutrition and light (Dana, 1980).

The fruits are borne on terminal inflorescences that develop on branch crowns. Only one inflorescence grows from each branch crown, so that the number of branch crowns affects yield to a great extent. The first inflorescence that is initiated is the one on the main axis. If growing conditions are favorable, the crown that originated from the axil of the last leaf on the main axis may initiate an inflorescence, making it appear that the two flower clusters came from a single point. From the extension crown, another extension crown may develop and initiate an inflorescence that will be very near the origin of the previous inflorescence (Dana, 1980).

A plant can have several branch crowns and fruit clusters. According to Dana (1980), given an equal number of crowns per acre, multi-crowned plants in a spaced planting system seem to be more productive than the same number of single-crown plants found in the matted row system. Scott et al. (1980) also observed that some varieties producing many clusters per plant but few berries per cluster have larger berries and high yields. It appears that competition between plants has a greater negative effect on yield than competition among crowns in the plant, within certain limits.

While some researchers include the number of crowns in analyses of yield components, Guttridge and Anderson (1981) obtained variable counts of branch crowns that resulted in misleading figures for clusters per crown. They suggest that a direct measurement of plant size is needed in evaluating the yield components of a cultivar, along with number of clusters and fruits and fruit weight.

Number of Fruits

Normally, an inflorescence will have one primary flower, two secondary flowers, four tertiary flowers, and if present, eight quaternary flowers (Dana, 1969). Not all of these develop into fruit. When they do, the primary fruit is usually the largest and the succeeding fruits are progressively smaller. Plant vigor and the existing environmental conditions determine the number of flowers that are produced within an inflorescence and the number of fruits that develop. A healthy plant can produce larger clusters than an unhealthy plant (Dana, 1969). Also, on most varieties, about one-third of the last flowers on each cluster may not form fruit although they may appear to be normal (Scott et al., 1980).

The number of fruits per plant is a useful measure of yield. Fruit number and fruit size have been found to be significantly correlated with yield, although yield was more dependent on number than on size (Lacey, 1973). Strik and Proctor (1988) also found that yield per plant within genotypes was mainly dependent on the number of berries per plant.

The number of primary and secondary fruits, however, is usually more important than the total number of fruits per plant. According to Scott et al. (1980), some varieties produce few berries per cluster but many clusters per plant, resulting in larger berries and higher yields.

Weight per Fruit

The fruits in a cluster differ in size. The primary fruit is usually the largest and heaviest. Darrow (1966) cites reports showing that the primary fruit in a cluster is the largest and that the secondary, tertiary, and quaternary fruits averaged 80%, 47%, and 32% the size of the primary fruit. In one variety, the secondary and tertiary fruits were on the average 48% and 33% the size of the primary fruit. Some clusters branch at the base rather than high in the inflorescence. Secondary berries from basal branching clusters were 91% of the primary fruit by weight. It appears that more large fruit are obtained from plants with basal branching inflorescences than from those with high branching clusters.

Sherman and Janick (1966) found that the weight of the single primary berry was similar to the combined weight of the two secondary berries and the combined weight of the four tertiary berries on pruned plants of 30 strawberry varieties. Genetic studies involving selfing, diallel cross, and crosses to variety and species testers showed that fruit size may be controlled by multiplicative gene action, with dominance effects accounting for any deviations in size distribution among the progenies (Sherman et al., 1966).

The number of pollinated pistils, and hence the number of achenes, affects the size of the fruit. Primary fruits are not only the largest but have the most seeds. In one variety, 382, 224, 151, and 92 seeds were counted successively for the primary, secondary, tertiary and quaternary fruits (Valleau, 1918 as cited in Darrow, 1966). In 'Gandy', an average of 518 pistils for the primary, and 83 for the last flowers were reported (Gardner, 1923 as cited in Darrow, 1966).

The fruit increases in size from pollination to full maturity. Darrow (1966 as cited in Dana, 1980) showed an increase of 143% from white berry stage to full ripe stage, and 14% from full red to full ripe stage.

Other Factors Related to Yield

Number of Leaves or Vigor

Yield is influenced by the amount of leaf surface area, with greater leaf area usually associated with higher yield. According to Dana (1980), each branch crown can produce a leaf surface that can support an inflorescence. However, too many leaves within a limited space may result in competition and yield reduction.

Short photoperiods and low temperatures in the fall reduce leaf growth in strawberries. Olsen et al. (1985) observed reduced rates of increase in leaf area per mother plant in the fall when the light period was about 12 h and the temperature was around 50°F. In fruiting plants, less dry matter was partitioned to the leaves than to the crowns and roots of the plant.

Strik and Proctor (1988) found that crown dry weight and leaf area after harvest were correlated with yield. When interplant competition was present, as when plants are grown in matted rows, vegetative variables were highly correlated with yield. The correlation between leaf variables and yield suggests that variation in photosynthesis may be important during flower bud development and fruiting.

Lacey (1973) collected vegetative data that included plant size or vigor and leaf number. His findings indicate that leaf number and plant size are correlated with some yield components, suggesting that the extent of vegetative growth affected yield. However, high leaf number before fruiting is likely to result in high yield. Large plants with fewer but larger leaves would tend to have similar yield but larger fruits.

Number of Runners

Runners arise from axillary buds that are released from dormancy by particular environmental conditions. According to Dana (1980) stolon production is generally a long day response. The first runner usually develops from the axil of the first new leaf initiated on the extension crown.

Runner production during fruit production is not a desirable trait because the runners compete with the fruit for assimilates. Strik and Proctor (1988) observed a negative relationship between stolon dry weight and the reproductive variables inflorescence number, inflorescence dry weight, and berry number in two genotypes evaluated. It appeared that when the plants were fruiting, the development of runners was reduced. These results suggest that there was competition for assimilates between runnering and fruiting in these genotypes.

In the diploid wood strawberry, runnering is controlled by a dominant Mendelian gene (Galletta and Himelrick, 1990). The expression of the runnering characteristic in cultivated strawberries is more complex. Janick and Moore (1996) cited reports showing highly variable rates of runner production among cultivars and wild collected clones of *F. vesca*, *F. chiloensis*, and *F. virginiana*. Nonrunnering was highly heritable in *F. x ananassa* and was closely correlated with the everbearing character.

Firmness

Firmness has become of increasing importance because of the need to transport fruit from areas of production to areas more accessible to consumers. According to Moore and Sistrunk (1980), a cultivar must have "shipping ability" so that it will be successful in the fresh market. Shipping ability refers to the capacity of the fruit to maintain a fresh, sound, and attractive condition after grading, packing, storage, and transport. Before the development of 'Wilson' in 1951, strawberries in the United States had to be commercially produced in areas near large cities so that the fruit need not be shipped long distances (Moore and Sistrunk, 1980).

Flesh firmness and skin toughness are separate, but related characters. Both are necessary if fruit with shipping ability is desired (Janick and Moore, 1996). Fruit firmness is greatly affected by temperature and humidity during fruit development and ripening (Scott et al., 1980 and Janick and Moore, 1996). Strawberry fruit harvested when temperatures are cool are firmer than those that ripen during warm humid weather

(Scott et al. 1980). The increasing importance of fruit firmness is evident in the cultivars developed recently. Firmness is one of the traits mentioned in the release notices of 'Sweet Charlie' (Chandler et al., 1997a), 'Rosa Linda' (Chandler et al., 1997b), 'Joliette' (Khanizadeh et al., 1996), and 'Primetime' (Galletta et al., 1996).

Components of Variance and Heritability

Estimation of genetic parameters in strawberries has been conducted using different populations in different locations. Results regarding the inheritance of commercially important production traits have usually been variable. According to Shaw (1991), the variable results could be due to differing genetic materials, test environments, and methods of evaluation.

Earliness and Early Yield

The inheritance of earliness has been well studied. Reports of investigations on members of the Rosaceae, including apples, pears, and cherries, are numerous. In strawberries, most of the inheritance studies were conducted in the late 1960s to early 1970s. The lack of recent information may partly be due to the highly variable flowering behavior of clones under different environmental conditions that make studying earliness complicated. One other reason may be the relative ease, at present, of manipulating flowering in strawberries so that clones bloom earlier simply by changing the growing conditions.

Earliness has also been referred to as precocity (Visser, 1976). In peaches, accelerating sexual maturation involves eliminating sexual repression, which is considered a "hallmark of juvenility" (Hansche et al., 1986). Measures of earliness include length of the juvenile period (Visser, 1976), time of bloom (Hansche et al., 1966), and ripening or harvest date (Abe et al., 1993 and Tancred et al., 1995).

In strawberries grown in Florida, high yield early in the season is more relevant to growers than simply a short juvenile period resulting in early flowering. Early yield has been evaluated in several ways. Watkins and Spangelo (1968) used the first pick to measure early yield. Other measures of early yield include the first two picks (Watkins et al., 1970 and Spangelo et al., 1971) and the harvest during the first two months (Hansche et al., 1968).

Estimates of narrow sense heritability (h^2) for earliness and early yield in strawberries and some of its relatives are generally high. This is an indication that mostly additive genetic effects govern earliness. In apples and pears, an analysis of variance of the juvenile period showed a highly significant general combining ability, which led Visser (1976) to assume that the mode of inheritance of the juvenile period is largely additive. Aalders and Craig (1974) obtained an additive genotypic variance for mean date of harvest in strawberries of 83%. Estimates of h^2 for earliness and early yield in several crops are shown in Table 2-1.

Yield and Its Components

Numerous studies have been conducted on the genetic parameters of yield and its components. Estimates are available for numbers of crowns, inflorescences, and fruits, fruit weight, and yield. Generally, heritability estimates for yield are relatively lower than estimates for earliness. Yield components, however, usually have higher heritability estimates than yield.

Table 2-1. Estimates of h^2 for earliness or early yield in some crops.

Crop	h^2	Source
Strawberries		
Yield in 1st two months	0.48	Hansche et al., 1968
Yield in 1st two picks	0.56 (random model)[1] 0.83 (mixed model)[2]	Spangelo et al., 1971
	0.39	Watkins et al., 1970 cited in Spangelo et al., 1971
Sweet cherry		Hansche et al., 1966
First bloom	0.65	
Full bloom	1.00	
Ripe date	0.88	
Peach		Hansche, 1986
Flower number	0.16	
Fruit number	0.33	
Pear		
Ripening date	0.95	Abe et al., 1993
Apple		
Ripening date	0.94	Tancred et al., 1995

[1] Male and female parents were considered random samples from the cultivated strawberries in North America.

[2] Male parents were considered random samples, female parents were considered fixed.

Estimates of additive variance for the yield components number of inflorescences, number of fruits, and fruit size are shown in Table 2-2. Estimates for this type of genetic variance were usually high.

Table 2-3 and 2-4 show estimates of heritability for number of fruits and fruit size. These estimates were taken using different populations grown under different conditions, and are therefore highly variable.

Fruit size has been evaluated using different methods. The simplest methods are dividing the berry number by the flower stalk number (Spangelo et al., 1971) or dividing

Table 2-2. Additive genetic variances for some yield components.

Trait	Additive variance (%)	Source
Flower stalk number	54-29	Watkins et al., 1970
	80-61	Watkins and Spangelo, 1971
Number of fruits	78-58	Watkins et al., 1970
	70-47	Watkins and Spangelo, 1971
Berries per flower stalk	58-33	Watkins et al., 1970
Berry weight	50.5	Aalders and Craig, 1974
	69-46	Watkins et al., 1970

Table 2-3. Estimates of h^2 for number of fruits.

Trait	h^2	Source
Berry number	0.11 (random model)[1] 0.29 (mixed model)[2]	Spangelo et al., 1971
Berries/ flower stalk	0.37 (random model) 0.64 (mixed model)	Spangelo et al., 1971

[1] Male and female parents were considered random samples from the cultivated strawberries in North America.

[2] Male parents were considered random samples, female parents were considered fixed.

Table 2-4. Estimates of h^2 for fruit size.

h^2	Source
0.42 (random model)[1] 0.72 (mixed model)[2]	Spangelo et al., 1971
0.28 (1985) 0.14 (1986)	Shaw et al., 1989
0.32 (Winters) 0.31 (Watsonville)	Shaw, 1989a
0.20	Hansche et al., 1968

[1] Male and female parents were considered random samples from the cultivated strawberries in North America.

[2] Male parents were considered random samples, female parents were considered fixed.

total yield by fruit number (Shaw et al., 1989). Hansche et al. (1968) and Larson and Shaw (1995) used the average per fruit weight of a 10-fruit sample to calculate fruit size, except that the latter used the weighted average of samples obtained weekly throughout the season, with weighting based on corresponding weekly yield.

Fruit size has relatively high additive variance (Table 2-2) and heritability (Table 2-4). According to Bringhurst and Voth (1980), high estimates of these genetic parameters of fruit size can be obtained if interplant competition is minimized, such as in the properly spaced hill system of culture used in California.

Additive variance estimates for yield are generally high, but heritabilities are highly variable. Based on four different assumptions about the presence or absence of epistatic variance and the source of environmental variance, Watkins et al. (1970) obtained additive variance estimates of 48-71%, 43-67%, and 44-68% for total yield, marketable yield, and late yield, respectively. Watkins and Spangelo (1971) estimated additive variance for marketable yield at 61-80%. Aalders and Craig (1974), however, obtained a value of 3.2%, a very low estimate for total yield. Table 2-5 shows heritability estimates for yield. The values range from a low of 0.10 for total yield, to a very high 0.97 for yield per flower stalk.

Vegetative Traits

More emphasis has been placed on the study of production traits than vegetative traits so that there are not many estimates of genetic variance and heritability for the latter. Plant vigor has been used to indicate high-yielding ability, although Shaw (1993) states that high vigor does not necessarily mean high yield. Vigor has been measured using subjective ratings of 1-5 (Watkins et al., 1970) or 1-10 (Spangelo et al., 1971) based on plant height, spread, and leaf density. Plant size has also been used to measure vigor. Shaw (1993) obtained plant diameters at three stages of growth within a growing season, from planting to winter rest, prior to the development of fruiting structures, and during flowering and production.

Table 2-5. Estimates of h^2 for yield.

Trait	h^2	Source
Total yield	0.17 (random model)[1] 0.10 (mixed model)[2]	Spangelo et al., 1971
Marketable yield	0.17 (random model) 0.16 (mixed model)	Spangelo et al., 1971
Late yield	0.38 (random model) 0.45 (mixed model)	Spangelo et al., 1971
Yield per flower stalk	0.60 (random model) 0.97 (mixed model)	Spangelo et al., 1971
Fruit yield (g/plant)	0.34 (1985) 0.36 (1986)	Shaw et al., 1989a

[1] Male and female parents were considered random samples from the cultivated strawberries in North America.

[2] Male parents were considered random samples, female parents were considered fixed.

Other vegetative traits that have been evaluated include leaf number (Larson and Shaw, 1995), number of petioles (Spangelo et al., 1971), and number of runners (Aalders and Craig, 1974). Aalders and Craig (1974) obtained an estimate of additive genotypic variance for number of runners per clone of 28%.

Firmness

The importance of fruit firmness has only recently gained attention so that there are few genetic studies on this trait. As early as 1968, however, Hansche et al. (1968) included fruit firmness in their evaluation of two strawberry cultivars. Firmness was measured by taking the number of grams of pressure needed to force a flat-faced rod with a diameter of 4.4 mm into the fruit. The trait was found to be moderately high to highly heritable, with h^2=0.46, and can be amenable to improvement through breeding.

Spangelo et al. (1971) evaluated firmness by pressing the fruit with the fingers. Fruit firmness was measured using a subjective rating scale of 1-7, with the high value being the firmest. Estimates of h^2 obtained were 0.10 for a random model and 0.26 for a mixed model.

Genetic Correlation and Indirect Selection

Studies regarding correlations between traits are important because they show how a change in one trait may affect another trait. There are three kinds of correlation: phenotypic, genetic, and environmental. Phenotypic correlation is the association between two traits that can be directly observed (Falconer, 1989). This type of correlation may arise from genotypic or environmental effects or a combination of the two. Bedard et al. (1971) states that phenotypic correlation is not very useful in selection unless genetic and environmental correlations between traits are in the same direction when estimated separately.

Genetic and environmental correlation are important in assessing separately the genetic and environmental causes of correlation. Falconer (1989) defines genetic correlation as the "correlation of breeding values", while environmental correlation is the "correlation of environmental deviations together with non-additive genetic deviations". Traits with low heritabilities are affected greatly by the environment. A high heritability, on the other hand, means that the environment has a smaller influence on the trait, and genetic correlation is more important. Falconer (1989) states that genetic and environmental correlations are usually of the same sign and do not differ greatly in magnitude. A large difference in size, and particularly a difference of sign, indicates that the trait is affected by the genotype and the environment through different physiological mechanisms.

A few studies dealing with correlation between traits in strawberries are cited here. Lacey (1973) calculated phenotypic correlations between 21 vegetative and fruiting characters of clones representing 100 random strawberry genotypes. Vegetative characters associated with yield were either correlated with fruit number (e.g. number of leaves during preceding autumn and winter) or with fruit size (e.g. plant size during the preceding seasons).

Bedard et al. (1971) estimated the three kinds of correlation among 28 fruit and plant traits. Significant positive genetic correlations were obtained between yield and several components. This indicates that yield may be improved by selecting indirectly for these individual components.

Shaw (1993) investigated the genetic and environmental relationships between vegetative growth and production traits at different periods in one cropping season. He found positive genetic correlations between fall growth increments and mid-season production traits, but negative or no correlation between fall growth and late-season production. On the other hand, growth during the production season (late spring and early summer) was negatively or not correlated to early production traits, but positively correlated to mid- and late-season production. The results suggest that breeding for early and sustained production may be conflicting objectives.

Nursery Selection

The size of a plant has been related to its ability to flower. Menges (1990) reports that a definite size threshold exists for sexual and asexual reproduction in *Laportea canadensis*, a clonal, monoecious, perennial herb that spreads by rhizomes. In an earlier study, he was able to predict with 90% accuracy whether a *Laportea* stem will sexually reproduce based on its aboveground size (Menges, 1983 as cited in Menges, 1990). He also referred to results of other studies showing a relationship between size and flowering for facultative biennials and perennial herbs, including ramets of clonal herbs.

Eriksson (1988) and Slade and Hutchings (1989) observed a positive relationship between ramet size and flowering in *Potentilla anserina* and *Glechoma hederacea*. Both species have rosette growth habits and reproduce sexually and through the production of stolons. Eriksson (1988) suggests that stolon, and probably flower, initiation occurs when a certain resource level within a ramet is reached.

In strawberries, Albregts and Howard (1985) found that the number of leaves on a plant when it is set out in the field affected its size during the season, and eventually its yield. Each cultivar had an optimum leaf number for optimum early and total fruit yield. While response differed by cultivar, the general trend was an increase in early and total yields with an increase in the number of leaves, up to a certain limit. Similarly, Mason

(1987) observed a proportional increase in the percentage of plants that flowered in the first year with an increase in the mean runner weight of the size grade. Runners from one site that were larger and had more developed inflorescence initials produced more inflorescences per plant than did runners from another site. Axillary bud development, flower initiation, and the number of potential fruit clusters in dissected runners from different sites were positively correlated with crown diameter or plant size.

It is clear from these reports that larger plant size usually favor increased flowering. What is not clear is whether the size of the mother plant will affect the ability of the daughter plants to flower. In other words, could the appearance of the seedling mother plant be used to predict the performance of the clone or daughter plant?

Nutrient sharing has been observed to occur among connected ramets. In *Fragaria chiloensis* grown in the greenhouse, Alpert (1991) found that resources were transported among connected ramets in either an acropetal or basipetal direction and can increase the growth of clonal plants. In nature, large net transfers of nitrogen occurred only from older to younger ramets and caused a substantial increase in the total biomass of younger ramets (Alpert, 1996). Furthermore, nitrogen acquired by the roots supports growth of both a rooted ramet and its new ramets (Alpert, 1991). Archbold and MacKown (1997) assert that roots are not temporary nitrogen storage sites. Nitrogen in the roots is not re-allocated to other tissues although this nutrient may be cycled through them. Rather, nitrogen from the leaflets was primarily remobilized to other tissues. Since nitrogen is the primary nutrient applied to and used by strawberry, nitrogen allocation and cycling within the plant may significantly influence plant vigor and productivity. This suggests that vigorous mother plants may produce more vigorous daughter plants than non-vigorous mother plants.

On the other hand, Wijesinghe (1994) observed that connected ramets in the stoloniferous perennial herb *Potentilla simplex* may show different levels of physiological interdependence. Ramets that used to be physiologically dependent on others may become independent over time. Or, one or several connected ramets may be independent from a very early stage. These differences may enable clone parts to adapt to local conditions without compromising the performance of the entire clone.

High vigor, however, does not always indicate high productivity. Shaw (1993) found that more vegetative growth in the fall resulted in larger yields in the middle of the season. However, there was negative or no correlation between fall growth and late-season production. Also, there was negative or no correlation between growth during the season and early production traits.

While it appears that a genetic switch triggers flowering when a plant reaches a certain size, flowering may also be influenced by specific environmental factors. In *Laportea*, Menges (1990) observed that clonal reproduction was related to stem density, decreasing with an increase in the number of stems, but only in upland forests. In strawberries, the effect of genotype on flowering is confounded by the effect of temperature and daylength. A plant may have reached the proper size threshold and not flower because the correct number of inductive cycles has not been reached.

CHAPTER 3
MATERIALS AND METHODS

Plant Materials

Genotypes used as parents to make the crosses came from two sources, the Florida and California breeding programs. The cultivated octoploid strawberry is highly hermaphroditic so flowers have both male and female parts. Genotypes were thus designated as females and males to indicate their use in hybridization. The genotypes designated as female were selected from the University of Florida breeding program, and those designated as male from the University of California breeding program. The earliness and daylength response for most of the genotypes are listed in Table 3-1.

Two experiments were conducted, one in 1994-1995 and the other in 1995-1996. In the first experiment, five genotypes from the Florida program were crossed with six genotypes from the California program. The second experiment consisted of six females from Florida crossed with four males from California.

Experiment 1 (Cropping Season 1994-1995)

Thirty seedling families from crosses of five and six genotypes designated as female and male parents, respectively, were evaluated in the field in late fall of 1994 to spring 1995. Genotypes used as females were FL87-236, FL90-51, FL91-37, FL91-48, and 'Sweet Charlie', while those used as males were 'Anaheim', 'Camarosa', 'Carlsbad', 'Cuesta', 'Laguna', and 'Sunset'.

One daughter plant from each of 28 seedlings from each family was dug from the summer nursery. The plants were set out in the field on November 4, 1994. Plots consisting of four plants each from the same family were laid out in a randomized complete block design with seven blocks. Daughter plants from the parental genotypes were also planted in the field.

Table 3-1. Strawberry genotypes used as female and male parents.

Genotype	Traits
Female parents	
FL87-236	Early, short day
FL89-123	Day neutral
FL90-10	Early, short day
FL90-51	
FL91-37	
FL91-48	
FL92-28	Late, short day
Rosa Linda	Early, short day
Sweet Charlie	Early, short day
Male parents	
Anaheim	
Camarosa	Early, short day
Carlsbad	
Cuesta	Late, short day
Laguna	
Oso Grande	Late, short day
Selva	Early, day neutral
Sunset	

Data on number of runners and yield were collected on a plot basis, but were later corrected to a plant basis since the number of plants per plot did not remain constant throughout the season. Crowns were counted on two plants per plot. Vigor was rated 1 to 5 based on the appearance of the plants in a plot, with the higher scores denoting greater vigor. Ratings were taken four times, starting from about a month after planting and every two weeks afterwards. Fruit firmness was rated six times during the growing season, using a scale of 1 (soft) to 5 (very firm).

Variance components for female (σ^2_f), male (σ^2_m) and female x male interaction (σ^2_{fm}) effects were obtained using PROC MIXED in SAS (SAS Institute, 1989-1996) with the block effect fixed and all other effects random. The expected mean squares are shown in Table 3-2. Genetic variances and heritability estimates of the traits evaluated were calculated from these variance components on an entry-mean basis, using the following equations from Hallauer and Miranda (1981):

1) additive genetic variance

$$\sigma^2_{af} = 4\sigma^2_f \qquad \sigma^2_{am} = 4\sigma^2_m$$

2) additive dominance variance

$$\sigma^2_d = 4\sigma^2_{fm}$$

3) narrow sense heritability

$$h^2_f = 4\sigma^2_f / \{4\sigma^2_f + (4\sigma^2_{fm}/m) + (\sigma^2/bm)\}$$

$$h^2_m = 4\sigma^2_m / \{4\sigma^2_m + (4\sigma^2_{fm}/f) + (\sigma^2/bf)\}$$

where the subscripts "f" and "m" stand for female and male, respectively, and the terms "b", "f", and "m" in the denominator correspond to the number of blocks, females and males, respectively.

Table 3-2. Expected mean squares for a mixed model with data taken on a plot basis (Experiment 1).

Source of variation	df	Expected mean squares
Block	b-1 = 6	
Female	f-1 = 4	$\sigma^2 + b\sigma^2_{fm} + bm\sigma^2_f$
Male	m-1 = 5	$\sigma^2 + b\sigma^2_{fm} + bf\sigma^2_m$
Female x male	(f-1)(m-1) = 20	$\sigma^2 + b\sigma^2_{fm}$
Experimental error	(b-1)(fm-1) = 174	σ^2
Total	bfm-1 = 209	

Experiment 2 (Cropping Season 1995-1996)

Using a 6x4 factorial mating design, 10 strawberry lines and cultivars were crossed in 1994-1995 to produce 24 families. FL87-236, FL89 -123, FL90-10, FL92-28, 'Rosa Linda', and 'Sweet Charlie' were used as female parents, while 'Camarosa', 'Cuesta', 'Oso Grande', and 'Selva' were used as male parents. Hybrid seeds were sown in trays in the greenhouse. The seedlings were transferred to peat pellets after about a month in the trays.

Selection in the Nursery

Approximately 300 seedlings per family were transplanted in the field nursery on July 24 and 25, 1995. Seedlings from each family were planted in a single row in a serpentine design. Plants were spaced 60 cm apart.

Selection was done on September 28, 1995, when the seedlings had been in the nursery for about two months. The seedlings in each family were randomly divided into two groups. The first group consisted of 100 plants from which 20 of the most vigorous plants were chosen and tagged. Selection was done by visual inspection. Selected plants generally had bigger and darker green leaves, and thicker crown bases. The second group consisted of the rest of the seedlings from which 20 plants were taken randomly. These 20 were designated the randomly picked plants.

Field Trial

One daughter plant from each of the selected and randomly picked plants was dug from the nursery a few days before planting. These daughter plants were set out in double rows in sterilized beds covered with plastic mulch on October 24, 1995. The 20 plants from the selected and randomly picked groups in each family were divided into five groups of four plants each and then assigned to five blocks. Blocks consisted of 48 plots with four plants each. Plots were spaced 60 cm apart and plants spaced 30 cm apart in the plot.

Data Gathered

In the nursery, the vigor of the 20 selected and 20 randomly picked seedlings from each family was rated just before daughter plants were dug for planting in the fruiting field. Branch crowns and runners of these plants were also counted. In the fruiting field, data were gathered on vigor, number of crowns, runners and inflorescences, and marketable yield. Vigor was rated 1 (least vigorous) to 5 (most vigorous). Branch crowns were counted when they had one leaf approximately 7.6 cm across.

Firmness was determined by applying pressure on the fruit using the thumb and forefinger. Fruits were rated 1 (soft) to 5 (very firm). Samples for firmness evaluation were taken twice during the peak of production. Three fruits from each plant were rated for firmness. Fruits rated were more or less of the same size and degree of ripeness.

Statistical Analysis

Data from the randomly picked set were analyzed using PROC MIXED in SAS (SAS Institute, 1989-1996) with block effects fixed and all other effects random. The expected mean squares for the linear model is shown in Table 3-3. Components of variance for female, male, and female x male interaction effects were used to calculate additive and dominance variances, as in Experiment 1. Narrow sense heritability for the traits evaluated was also obtained. Heritability estimates on an individual and on an entry-mean basis were derived. Equations used for calculating heritability on an individual basis were also from Hallauer and Miranda (1981):

$$h^2_f = 4\sigma^2_f /(\sigma^2_f + \sigma^2_m + \sigma^2_{fm} + \sigma^2_w)$$

$$h^2_m = 4\sigma^2_m /(\sigma^2_f + \sigma^2_m + \sigma^2_{fm} + \sigma^2_w)$$

where σ^2_w corresponds to within-plot variance. Two estimates of additive variance and narrow sense heritability were obtained due to the presence of female and male sources of variation. Genetic correlation was estimated using components of covariance obtained from an analysis of covariance.

The selected and unselected plants in each family were compared to determine if it is feasible to do selection in the nursery. Data from both sets were analyzed using PROC GLM in SAS, with set considered fixed and female and male random.

Table 3-3. Expected mean squares for a mixed model with data taken on individual plants (Experiment 2).

Source of variation	df*	Expected mean squares
Block	b-1 = 4	
Female	f-1 = 5	$\sigma^2_w + kb\sigma^2_{fm} + bm\sigma^2_f$
Male	m-1 = 3	$\sigma^2_w + kb\sigma^2_{fm} + bf\sigma^2_m$
Female x male	(f-1)(m-1) = 15	$\sigma^2_w + kb\sigma^2_{fm}$
Experimental error	(b-1)(fm-1) = 92	$\sigma^2_w + kb\sigma^2$
Within plot	bfm(k-1) = 360	σ^2_w
Total	bfmk-1 = 479	

* k = no. of plants per plot = 4.

CHAPTER 4
YIELD COMPONENT ANALYSIS

Yield component analyses are common in strawberries (Bedard et al., 1971; Swartz et al., 1985; Strik and Proctor, 1988; and Baumann et al., 1993). These are usually performed to evaluate the productivity of different genotypes. Measurements taken on yield components are analyzed to determine how the components are associated with yield.

In this research, a yield component analysis was performed to determine the relationship of several vegetative and reproductive traits to yield. Using data from cropping season 1995-1996, four measures of yield were designated as dependent variables, namely, 1) marketable fruit weight in January, 2) total fruit weight in January, 3) marketable fruit weight for the season, and 4) total fruit weight for the season. Total yield in January and for the whole season included fruit that were classified as culls due to small size, disease or unacceptable shape. The four measures of yield were regressed on several vegetative and reproductive traits. The equations used to calculate the regression coefficients are shown in Table 4-1.

In the first two regression equations, independent variables consisted of vegetative traits and number of inflorescences. These analyses were conducted to determine which of these traits, if any, would contribute significantly to January yield. Among the four traits included in the equation, only number of inflorescences 79 DAP had a significant

Table 4-1. Equations used to calculate R^2 in multiple regression of yield.

Regression	Equation	R^2
1	Jan. marketable wt. = 21.13 - 0.64 no. of crowns 85 DAP + 21.94 no. of inflorescences 79 DAP** + 0.61 no. of runners 83 DAP + 0.94 vigor 72 DAP	0.06
2	Jan. total wt. = 25.77 - 1.16 no. of crowns 85 DAP + 23.01 no. of inflorescences 79 DAP** + 0.13 no. of runners 83 DAP + 1.03 vigor 72 DAP	0.06
3	Season marketable wt. = -108.11 + 3.71 no. of crowns 113 DAP - 1.53 total no. of inflorescences + 11.54 no. of runners 83 DAP + 36.28 vigor 114 DAP* + 23.66 no. of marketable fruit in January** + 9.25 ave. fruit wt. in January**	0.34
4	Season total wt. = -39.50 + 3.82 no. of crowns 113 DAP - 2.66 total no. of inflorescences + 10.72 no. of runners 83 DAP + 50.35 vigor 114 DAP* + 28.16 no. of marketable fruit in January** + 7.86 ave. fruit wt. in January**	0.27

* Significantly different from zero at *P*=0.05.

** Significantly different from zero at *P*=0.01.

contribution to both January marketable and total weight. The R^2 values were very low, however, indicating that these models cannot be used to satisfactorily predict the dependent variables January marketable and total weight.

In equations 3 and 4, January marketable number and average fruit weight had significant contributions to the whole season marketable and total weight. Vigor 114 DAP was also a significant component in the models, suggesting that higher plant vigor later in the season is important in obtaining higher total season yield. Values of R^2 were low but significant, indicating that the model can be used to satisfactorily predict the dependent variables season marketable and total weight.

These results have considerable implications for the evaluation of new clones in a breeding cycle. Due to the large number of clones being evaluated in initial fruiting field trials, the January yield of each clone is not measured (Chandler, personal communication). The regression analyses show the significant contribution made by two measures of yield, namely number of fruit and average fruit weight in January, on whole season yield. If emphasis is to be placed on breeding for high early yield, then it may be necessary to consider fruit yield in January in addition to whole season yield in future evaluations.

A correlation analysis was conducted involving some vegetative and production traits. Correlation coefficients among vegetative traits are shown in Table 4-2. There is high correlation among vigor ratings taken during different times of the season. This result is expected because plants that are vigorous early in the season will be more likely to remain so later in the season. Vigor throughout the season was also highly correlated with the number of crowns counted at three different times during the early part of the

Table 4-2. Correlation coefficients among vegetative traits (1995-1996).

Traits	1	2	3	4	5	6
1 Vigor 30 DAP						
2 Vigor 44 DAP	0.63 ***					
3 Vigor 58 DAP	0.55 ***	0.73 ***				
4 Vigor 72 DAP	0.40 ***	0.67 ***	0.77 ***			
5 Vigor 86 DAP	0.32 ***	0.61 ***	0.71 ***	0.85 ***		
6 Vigor 100 DAP	0.27 ***	0.53 ***	0.62 ***	0.76 ***	0.79 ***	
7 Vigor 114 DAP	0.24 ***	0.52 ***	0.62 ***	0.75 ***	0.79 ***	0.84 ***
8 No. of crowns 57 DAP	0.35 ***	0.46 ***	0.56 ***	0.55 ***	0.50 ***	0.41 ***
9 No. of crowns 85 DAP	0.23 ***	0.43 ***	0.52 ***	0.62 ***	0.61 ***	0.57 ***
10 No. of crowns 113 DAP	0.29 ***	0.45 ***	0.50 ***	0.56 ***	0.59 ***	0.67 ***
11 No. of runners 83 DAP	0.11 *	0.16 ***	0.10 *	-0.00 ns	-0.03 ns	-0.05 ns
12 Total no. of runners	0.11 *	0.14 **	0.09 ns	-0.02 ns	-0.04 ns	-0.07 ns

* Significantly correlated at *P*=0.05.

** Significantly correlated at *P*=0.01.

*** Significantly correlated at *P*=0.001.

ns Correlation not significant.

Table 4-2. Continued.

Traits	7	8	9	10	11
8 No. of crowns 57 DAP	0.44 ***				
9 No. of crowns 85 DAP	0.60 ***	0.63 ***			
10 No. of crowns 113 DAP	0.63 ***	0.46 ***	0.61 ***		
11 No. of runners 83 DAP	-0.02 ns	-0.08 ns	-0.26 ***	-0.05 ns	
12 Total no. of runners	-0.04 ns	-0.08 ns	-0.27 ***	-0.06 ns	0.99 ***

season. This is not surprising, considering that vigor was rated visually. More crowns would give rise to a more vigorous-looking plant.

Runners were counted twice during the season, at 83 DAP and 160 DAP. Since very few runners were produced between the first and second counts, data during the second count were not included in the analysis. The very high correlation between number of runners 83 DAP and the total number of runners (0.99) suggests, however, that the runners produced from the time plants were transplanted up to 83 DAP make up most of the total number of runners. The number of runners is positively correlated with early vigor, and negatively correlated with number of crowns 85 DAP. The number of crowns is considered a vegetative trait in this research, but it is related to fruit production because the number of crowns will affect the number of inflorescences produced. Strik and Proctor (1988) found a negative correlation between stolon dry weight and some reproductive variables. They state that when the reproductive sink is large, runner development declines. This may indicate the presence of competition for assimilates between runners and crowns.

Correlation coefficients among vegetative and reproductive traits are listed in Table 4-3. Most of the correlation coefficients are low but some are still significant at P=0.05. For instance, vigor 58 DAP and number of marketable fruit in March have a correlation coefficient of 0.11. This low but significant correlation between the two traits is an indication that some other factors may be affecting the number of marketable fruit in March in addition to vigor.

The vegetative traits vigor and number of crowns were significantly correlated with several reproductive traits. Since vigor and number of crowns were found to be

Table 4-3. Correlation coefficients among vegetative and reproductive traits (1995-1996).

Traits	Vigor					
	30DAP	44DAP	58DAP	72DAP	86DAP	100DAP
No. of inflorescences 79 DAP	0.20 ***	0.07 ns	0.09 ns	0.05 ns	0.03 ns	-0.07 ns
No. of inflorescences 107 DAP	-0.02 ns	0.05 ns	0.00 ns	0.03 ns	0.06 ns	0.05 ns
No. of inflorescences 135 DAP	0.17 ***	0.36 ***	0.38 ***	0.46 ***	0.48 ***	0.53 ***
No. of marketable fruit (January)	0.12 *	0.08 ns	0.03 ns	-0.01 ns	-0.01 ns	-0.04 ns
Marketable fruit wt. (January)	0.14 **	0.10 *	0.05 ns	0.02 ns	0.02 ns	-0.01 ns
Total fruit wt. (January)	0.13 *	0.09 ns	0.05 ns	0.01 ns	0.01 ns	-0.03 ns
Average fruit wt. (January)	0.04 ns	0.11 ns	0.08 ns	0.16 ns	0.16 ns	0.16 ns
No. of marketable fruit (February)	-0.01 ns	-0.00 ns	0.00 ns	-0.03 ns	0.00 ns	-0.04 ns
Marketable fruit wt. (February)	-0.03 ns	-0.02 ns	0.04 ns	0.02 ns	0.06 ns	0.03 ns
Total fruit wt. (February)	-0.00 ns	0.03 ns	0.04 ns	0.02 ns	0.05 ns	0.02 ns
Average fruit wt. (February)	-0.00 ns	0.07 ns	0.13 *	0.14 *	0.14 *	0.16 **
No. of marketable fruit (March)	-0.01 ns	0.08 ns	0.11 *	0.17 **	0.21 ***	0.20 ***
Marketable fruit wt. (March)	-0.00 ns	0.10 ns	0.15 **	0.19 ***	0.22 ***	0.22 ***
Total fruit wt. (March)	-0.00 ns	0.10 *	0.15 **	0.21 ***	0.24 ***	0.24 ***
Average fruit wt. (March)	0.03 ns	0.05 ns	0.12 *	0.04 ns	0.03 ns	0.04 ns
Season no. of marketable fruit	0.01 ns	0.09 ns	0.11 *	0.14 **	0.19 ***	0.16 **
Season marketable fruit wt.	0.02 ns	0.12 *	0.16 **	0.17 **	0.21 ***	0.20 ***
Season total fruit wt.	0.03 ns	0.12 *	0.16 **	0.19 ***	0.23 ***	0.21 ***
Season average fruit wt.	0.06 ns	0.11 *	0.15 **	0.10 ns	0.09 ns	0.12 *

* Significantly correlated at *P*=0.05.

** Significantly correlated at *P*=0.01.

***Significantly correlated at *P*=0.001.

ns Correlation not significant.

Table 4-3. Continued.

Traits	Vigor	No. of crowns			No. of runners	
	114DAP	57DAP	85DAP	113DAP	83DAP	Total
No. of inflorescences 79 DAP	-0.13 **	0.20 ***	-0.09 ns	-0.24 ***	-0.12 *	-0.12 *
No. of inflorescences 107 DAP	0.06 ns	0.09 ns	0.30 ***	-0.02 ns	-0.07 ns	-0.08 ns
No. of inflorescences 135 DAP	0.57 ***	0.39 ***	0.53 ***	0.72 ***	-0.06 ns	-0.07 ns
No. of marketable fruit (January)	-0.11 *	0.00 ns	-0.07 ns	-0.12 *	0.00 ns	0.00 ns
Marketable fruit wt. (January)	-0.07 ns	0.01 ns	-0.04 ns	-0.10 ns	-0.01 ns	-0.01 ns
Total fruit wt. (January)	-0.08 ns	0.01 ns	-0.06 ns	-0.11 ns	-0.02 ns	-0.02 ns
Average fruit wt. (January)	0.24 **	0.02 ns	0.20 *	0.12 ns	-0.05 ns	-0.06 ns
No. of marketable fruit (February)	-0.06 ns	-0.04 ns	-0.03 ns	-0.04 ns	-0.00 ns	0.01 ns
Marketable fruit wt. (February)	0.00 ns	-0.01 ns	0.03 ns	0.01 ns	-0.02 ns	-0.02 ns
Total fruit wt. (February)	-0.02 ns	-0.02 ns	0.02 ns	-0.01 ns	-0.03 ns	-0.03 ns
Average fruit wt. (February)	0.13 *	0.10 ns	0.14 *	0.12 *	0.02 ns	0.01 ns
No. of marketable fruit (March)	0.21 ***	0.11 *	0.16 **	0.19 ***	0.06 ns	0.05 ns
Marketable fruit wt. (March)	0.22 ***	0.13 *	0.18 **	0.21 ***	0.05 ns	0.04 ns
Total fruit wt. (March)	0.22 ***	0.12 *	0.18 ***	0.22 ***	0.04 ns	0.02 ns
Average fruit wt. (March)	0.03 ns	0.08 ns	0.06 ns	0.06 ns	-0.03 ns	-0.04 ns
Season no. of marketable fruit	0.15 **	0.08 ns	0.12 *	0.13 *	0.06 ns	0.05 ns
Season marketable fruit wt.	0.17 **	0.11 *	0.15 **	0.15 **	0.03 ns	0.02 ns
Season total fruit wt.	0.16 **	0.10 ns	0.16 **	0.16 **	0.01 ns	0.00 ns
Season average fruit wt.	0.06 ns	0.06 ns	0.08 ns	0.06 ns	-0.04 ns	-0.06 ns

* Significantly correlated at *P*=0.05.

** Significantly correlated at *P*=0.01.

***Significantly correlated at *P*=0.001.

ns Correlation not significant.

correlated (Table 4-2), the similar relationship of these two vegetative traits to some reproductive traits is not surprising.

Vigor 30 DAP and the number of inflorescences 79 DAP had a positive correlation. This suggests that daughter plants that recover quickly after transplanting have a better chance of producing inflorescences earlier in the season. The positive correlation between number of inflorescences 135 DAP and vigor 30 to 114 DAP, however, indicate that good vigor is necessary throughout the season to ensure prolific flowering.

The number of inflorescences and number of crowns were generally positively correlated. This is important if viewed in terms of higher potential yield. For instance, number of inflorescences 79 DAP is positively correlated with number of crowns 57 DAP, but negatively correlated with number of crowns 113 DAP. It appears that more inflorescences can be produced early if more crowns develop during the early part of the season, but more inflorescences early in the season may lead to less crown production later in the season. The coefficients between number of inflorescences 135 DAP and number of crowns counted at different times during the season showed an increasing trend, indicating that as more crowns developed with the progress of the season, more inflorescences were also produced.

With regards to yield, vigor 30 DAP was correlated with January yield. Vigor 58 to 114 DAP was correlated with March yield and season yield. Just as early vigor is important in early inflorescence production, it appears that early plant vigor is also important in early yield, and may lead to higher fruit yield later in the season. Plants that show vigor later in the season cannot be predicted to be good early, thus it is critical to evaluate the plants for vigor early in the season.

The number of crowns was significantly correlated only with March and total season yield. It appears that more crowns later in the season will result in higher March and total yield.

Number of runners and all reproductive traits generally had a negative correlation, but only the relationship with number of inflorescences 79 DAP was significant at $P=0.05$. This negative relationship between number of runners and number of inflorescences may be related to the relationship of the former with number of crowns as described in Table 4-2. Since a crown may produce only one inflorescence, any reduction in the number of crowns will lead to a reduction in the number of inflorescences produced.

Correlation coefficients among reproductive traits are in Table 4-4. Some of the relationships are obvious, such as the positive correlation between the number of inflorescences 79 DAP and the number and weight of marketable fruit and total fruit weight in January. Data on number of inflorescences 79 DAP were taken on January 11, and consist of all inflorescences produced from planting until that date. The same relationship is apparent between number of inflorescences 135 DAP (March 7) and total March yield and whole season marketable yield. Production of more inflorescences means a higher potential fruit yield. The number of inflorescences 107 DAP (February 8) generally had very low correlation coefficients and showed significant correlation only with number of inflorescences 135 DAP and with average fruit weight in January.

Table 4-4. Correlation coefficients among reproductive traits (1995-1996).

Traits	1	2	3	4	5	6
1 No. of inflorescences 79 DAP						
2 No. of inflorescences 107 DAP	-0.27 ***					
3 No. of inflorescences 135 DAP	-0.23 ***	-0.14 **				
4 No. of marketable fruit (January)	0.28 ***	-0.02 ns	-0.15 **			
5 Marketable fruit wt. (January)	0.25 ***	0.01 ns	-0.14 *	0.96 ***		
6 Total fruit wt. (January)	0.25 ***	-0.01 ns	-0.14 **	0.95 ***	0.98 ***	
7 Average fruit wt. (January)	-0.29 ***	0.19 *	0.11 ns	-0.32 ***	0.08 ns	0.04 ns
8 No. of marketable fruit (February)	0.08 ns	0.03 ns	-0.09 ns	0.21 ***	0.26 ***	0.28 ***
9 Marketable fruit wt. (February)	0.01 ns	0.03 ns	0.00 ns	0.03 ns	0.08 ns	0.10 ns
10 Total fruit wt. (February)	0.05 ns	0.02 ns	-0.03 ns	0.10 *	0.16 ***	0.17 ***
11 Average fruit wt. (February)	-0.18 **	-0.00 ns	0.20 ***	-0.45 ***	-0.44 ***	-0.45 ***
12 No. of marketable fruit (March)	0.18 ***	0.02 ns	-0.14 *	-0.17 ***	-0.16 **	-0.17 ***
13 Marketable fruit wt. (March)	0.12 *	0.03 ns	-0.06 ns	-0.18 ***	-0.16 **	-0.17 ***
14 Total fruit wt. (March)	-0.08 ns	-0.02 ns	0.18 ***	-0.17 ***	-0.16 **	-0.17 ***
15 Average fruit wt. (March)	-0.10 ns	-0.01 ns	0.18 ***	-0.10 *	-0.04 ns	-0.01 ns
16 Season no. of marketable fruit	-0.04 ns	-0.00 ns	0.18 ***	0.12 *	0.15 **	0.14 **
17 Season marketable fruit wt.	-0.09 ns	-0.01 ns	0.20 ***	0.11 *	0.17 ***	0.16 **
18 Season total fruit wt.	0.01 ns	-0.01 ns	0.11 ns	0.13 *	0.17 ***	0.17 ***
19 Season average fruit wt.	-0.01 ns	0.01 ns	0.12 *	0.02 ns	0.11 *	0.12 *

* Significantly correlated at *P*=0.05.

** Significantly correlated at *P*=0.01.

***Significantly correlated at *P*=0.001.

ns Correlation not significant.

Table 4-4. Continued.

Traits	7	8	9	10	11	12
7 Average fruit wt. (January)						
8 No. of marketable fruit (February)	0.36 ***					
9 Marketable fruit wt. (February)	0.48 ***	0.92 ***				
10 Total fruit wt. (February)	0.39 ***	0.93 ***	0.98 ***			
11 Average fruit wt. (February)	0.33 ***	-0.16**	0.26 ***	0.18 ***		
12 No. of marketable fruit (March)	0.11 ns	-0.03 ns	0.07 ns	0.04 ns	0.31 ***	
13 Marketable fruit wt. (March)	0.22 **	-0.05 ns	0.07 ns	0.04 ns	0.38 ***	0.96 ***
14 Total fruit wt. (March)	0.13 ns	-0.02 ns	0.09 ns	0.06 ns	0.35 ***	0.96 ***
15 Average fruit wt. (March)	0.37 ***	-0.04 ns	0.04 ns	0.03 ns	0.22 ***	0.03 ns
16 Season no. of marketable fruit	0.21 **	0.43 ***	0.45 ***	0.44 ***	0.14 *	0.87 ***
17 Season marketable fruit wt.	0.41 ***	0.46 ***	0.55 ***	0.54 ***	0.32 ***	0.80 ***
18 Season total fruit wt.	0.30 ***	0.46 ***	0.53 ***	0.54 ***	0.27 ***	0.80 ***
19 Season average fruit wt.	0.58 ***	0.16 **	0.35 ***	0.33 ***	0.50 ***	-0.04 ns

Table 4-4. Continued.

Traits	13	14	15	16	17	18
13 Marketable fruit wt. (March)						
14 Total fruit wt. (March)	0.96 ***					
15 Average fruit wt. (March)	0.26 ***	0.14 **				
16 Season no. of marketable fruit	0.82 ***	0.84 **	-0.01 ns			
17 Season marketable fruit wt.	0.83 ***	0.81 ***	0.23 ***	0.94 ***		
18 Season total fruit wt.	0.80 ***	0.84 **	0.13 *	0.95 ***	0.97 ***	
19 Season average fruit wt.	0.16 **	0.07 ns	0.80 ***	0.04 ns	0.34 ***	0.24 ***

February appears to be a transition month when January yield has just tapered off and the fruit that will be harvested in March is starting to grow and mature.

Average fruit weight in January was negatively correlated with number of inflorescences 79 DAP and number of marketable fruit in January. However, marketable and total fruit weights in January have high significant correlation with number of marketable fruit in January. It seems that average fruit weight will decrease with an increase in the number of inflorescences produced. Any decrease in average fruit weight will be accompanied by an increase in the number of fruit. These results show that an increase in the number of fruit will lead to higher January total yield. Apparently, higher marketable and total weight can be attributed more to a higher number of fruit than to bigger fruit. While more inflorescences would mean potentially more fruit, fruits will tend to become smaller as their number increases.

Number of inflorescences 79 DAP showed a negative correlation with number of inflorescences 107 and 135 DAP. High inflorescence production earlier in the season may limit or suppress later inflorescence production. This may be a disadvantage because it may limit total fruit production for the season. However, it may lead to higher yield in January, when strawberries command higher prices. The negative correlation between number of inflorescences 79 DAP and number of inflorescences 107 to 135 DAP may also indicate that a lower inflorescence production earlier in the season could lead to more inflorescences produced later in the season. If this occurs, there may be an increased yield in March.

The relationship between monthly inflorescence production is carried over to fruit yield. January yield is negatively correlated with March yield. However, there is a positive correlation between all measures of January yield and the number of marketable fruit in February. This indicates that high yield in January may be accompanied by high yield in February. However, this may give some preliminary evidence that a shift to earlier production does not also mean that the plants will produce for a longer period of time.

Monthly measures of yield were all positively correlated with whole season yield. This is an indication that increases in monthly yield will lead to an increase in whole season yield. Correlation coefficients increased as the months progressed, becoming higher in March than in January and in February. Thus, high early yield will still increase the total season yield, but perhaps by not as great an amount as increased yields in March. However, given the better price for strawberries in January, the grower may still do better financially with a lower final yield, assuming that any yield reduction occurs later in the season.

CHAPTER 5
COMBINING ABILITY

The selection of parental genotypes to use in making crosses is often complicated by the fact that the ability of these genotypes to pass on the desirable traits to their offspring, or their combining ability, is unknown. Estimates of combining ability for desirable traits can provide information that can be used to select parents and predict the performance of untested crosses (Simmonds, 1979).

One type of combining ability is general combining ability (GCA), which is defined as the average performance of a genotype in a series of hybrid combinations (Poehlman, 1977). GCA is expressed as a deviation from the overall mean of the crosses (Falconer, 1989). GCA estimates are most useful when a trait is inherited in an additive manner (Aalders and Craig, 1968). A second type is specific combining ability (SCA), which gives an indication of how a combination of two specific genotypes will perform in a particular cross. It is evaluated by determining the relation of the performance of that particular cross to the average performance of the genotypes in a series of crosses (Poehlman, 1977). SCA estimates are more useful for traits with a non-additive type of inheritance (Aalders and Craig, 1968).

In this study, genotypes designated as female and male were crossed in a factorial mating design. In the first cropping season, crosses were generated using a 5 x 6 factorial. In the second cropping season, six genotypes were used as females and four as males. The genotypes used as females are selections from the University of Florida strawberry breeding program, while the genotypes used as males are cultivars from the University of California breeding program (Table 5-1). These genotypes are representative of the parents currently being used in the UF strawberry breeding program. Also, the factorial sets of crosses made are a type commonly used in the program, i.e., where UF selections, which typically have desirable fruiting patterns, are crossed with UC cultivars, which tend to produce large, firm, and attractive fruit.

Table 5-1. Genotypes used as female and male parents.

Female	Male
Experiment 1 (1994-1995)	
FL87-236	Anaheim
FL90-51	Camarosa
FL91-37	Carlsbad
FL91-48	Cuesta
Sweet Charlie	Laguna
	Sunset
Experiment 2 (1995-1996)	
FL87-236	Camarosa
FL89-123	Cuesta
FL90-10	Oso Grande
FL92-28	Selva
Rosa Linda	
Sweet Charlie	

Analyses of variance were performed on data in both years using PROC GLM in SAS (SAS Institute, 1989-1996), with all effects considered fixed. Mean squares for female and male general combining ability for the traits studied are shown in Tables 5-2 and 5-3. More traits showed significant effects due to general combining ability in the female than in the male source of variation in both experiments. In the first year (Table 5-2) for instance, number of marketable fruit in February, average fruit weight in January

Table 5-2. Mean squares for general and specific combining ability in vegetative and production traits in strawberry grown in Dover, Florida (1994-1995).

Trait		MS_f[1]	MS_m	MS_{fm}
No. of runners	46 DAP	4.00 **	1.51 **	1.30 **
	91 DAP	1.17 **	1.04 **	0.31 ns
Total no. of runners		8.45 **	4.28 **	2.37 **
No. of crowns	92 DAP	21.69 **	7.33 **	2.84 *
Vigor	27 DAP	1.61 **	1.65 **	0.92 **
	42 DAP	3.06 **	2.20 **	1.68 **
	57 DAP	4.94 **	1.82 **	1.52 **
	69 DAP	3.98 **	0.97 *	1.74 **
No. of marketable fruit	January	7.89 **	2.92 **	0.79 ns
	February	22.22 **	5.56 ns	5.70 *
	March	61.92 **	54.11 **	27.42 *
	Season	220.50 **	74.26 *	39.43 *
Marketable fruit weight	January	8252.51 **	2774.19 **	674.99 ns
	February	8299.63 **	5538.16 *	3609.25 *
	March	35648.99 **	29554.62 **	13510.94 ns
	Season	135585.56 **	51817.82 **	22217.15 *
Total fruit weight	January	9107.73 **	3285.71 **	711.27 ns
	February	9581.76 **	6842.23 *	3914.56 *
	March	42129.82 **	36819.91 **	14537.33 ns
	Season	152903.41 **	64931.89 **	23410.46 ns
Average fruit weight	January	173.34 **	85.45 ns	37.78 ns
	February	53.47 *	20.64 ns	32.50 *
	March	9.59 ns	30.72 **	9.91 ns
	Season	20.31 *	19.68 *	6.16 ns
Fruit firmness	91 DAP	1.31 **	0.50 ns	1.83 *
	99 DAP	3.23 **	4.07 **	1.56 **
	106 DAP	4.27 **	3.28 **	0.43 *
	112 DAP	3.43 **	0.70 *	0.51 *
	119 DAP	3.22 **	1.67 **	0.29 **
	133 DAP	2.81 **	2.32 **	0.77 **

[1] ns, *, and ** refer to the results of the F-test and indicate no difference among means, and significant difference at *P*=0.05, and *P*=0.01, respectively.

and February, and fruit firmness 91 DAP showed significant to highly significant female effects and insignificant male effects. During the second year (Table 5-3), most of the differences in female-male effects were seen in vigor, season marketable and total fruit weight, and fruit firmness. The significant results indicate that means of at least two genotypes in both the female and male groups are different at *P*=0.05 or 0.01.

More traits had significant GCA effects for female and/or male than SCA effects. In the first cropping season, all traits had significant GCA effects, while 20 out of the 30 traits evaluated had significant SCA effects. In 1995-1996, only nine out of the 35 traits evaluated showed significant SCA effects, indicating that for the set of parents used in both cropping seasons, GCA effects were more important than SCA effects.

Simmonds (1979) used the proportion of the total sum of squares due to the parents to determine whether GCA or SCA accounts for the differences between crosses. Using this method, it appears that GCA effects due to the female and the male are more important than SCA effects in this study. Of the 30 traits evaluated in cropping season 1994-1995 (Table 5-4), more than half showed a higher combined (female + male) percentage of the sum of squares to be due to the parental effects. Combined female and male GCA effects accounted for 10.3 to 37.3% of total sum of squares in traits with more important GCA than SCA effects. Traits with important SCA effects include number of runners 46 DAP, vigor, marketable and average fruit weight in February, and fruit firmness 91 DAP. In cropping season 1995-1996 (Table 5-5), almost all of the 35 traits evaluated showed higher combined female and male GCA effects than SCA effects. Only vigor 44 and 58 DAP, and number of runners 160 DAP had more important SCA than GCA effects.

Table 5-3. Mean squares for general and specific combining ability in vegetative and production traits in strawberry grown in Dover, Florida (1995-1996).

Trait		MS$_f$[1]	MS$_m$	MS$_{fm}$
Vigor	30 DAP	2.08 **	1.17 *	0.30 ns
	44 DAP	2.56 **	0.29 ns	1.14 *
	58 DAP	1.96 **	0.81 ns	1.07 *
	72 DAP	4.06 **	2.35 *	1.33 *
	86 DAP	3.31 **	1.57 ns	0.94 ns
	100 DAP	4.08 **	2.38 *	0.83 ns
	114 DAP	4.37 **	4.57 **	0.67 ns
No. of crowns	57 DAP	7.12 **	4.34 *	2.36 ns
	85 DAP	11.86 **	29.45 **	1.75 ns
	113 DAP	45.65 **	186.09 **	15.39 ns
No. of runners	83 DAP	10.93 **	5.71 *	1.17 ns
	160 DAP	0.09 ns	0.19 **	0.11 **
Total no. of runners		9.46 **	7.81 **	1.28 ns
No. of inflorescences	79 DAP	1.78 **	2.43 **	0.20 ns
	107 DAP	1.32 *	1.69 *	0.58 ns
	135 DAP	13.44 *	53.53 **	2.08 ns
Total no. of inflorescences		14.19 **	28.94 **	2.65 ns
No. of marketable fruit	January	21.19 **	26.24 **	2.46 ns
	February	55.35 **	139.90 **	5.99 ns
	March	385.38 **	482.60 **	32.73 ns
	Season	598.86 **	169.19 ns	44.17 ns
Marketable fruit weight	January	15968.47 **	19697.11 **	1710.01 ns
	February	34636.57 **	29118.88 **	3785.57 ns
	March	122979.21 **	220240.86 **	8713.23 ns
	Season	279554.71 **	93755.21 *	9438.59 ns
Total fruit weight	January	17881.17 **	22157.01 **	2086.32 ns
	February	41240.49 **	42432.71 **	3772.23 ns
	March	170014.50 **	221499.12 **	15498.88 ns
	Season	369307.01 **	75845.75 ns	20226.83 ns
Average fruit weight	January	116.92 ns	32.93 ns	58.04 ns
	February	304.85 **	361.42 **	106.68 **
	March	22.21 *	57.71 **	14.09 *
	Season	22.97 *	42.11 **	16.42 *
Firmness	148 DAP	23.32 **	1.81 *	1.93 **
	153 DAP	12.96 **	0.61 ns	0.94 **

[1] ns, *, and ** refer to results of the F-test and indicate no difference among means, and significant difference at *P*=0.05, and *P*=0.01, respectively.

Table 5-4. Percentages of sums of squares due to general (GCA) and specific combining ability (SCA) in strawberry in Dover, Florida (1994-1995).

Trait		GCA	SCA
No. of runners	46 DAP	17.8	19.7
	91 DAP	13.7	8.6
Total no. of runners		19.6	16.8
No. of crowns	92 DAP	13.3	5.5
Vigor	27 DAP	17.6	21.9
	42 DAP	17.9	25.8
	57 DAP	24.7	25.9
	69 DAP	16.4	27.4
No. of marketable fruit	January	21.6	7.4
	February	13.5	13.2
	March	13.5	14.3
	Season	19.9	12.5
Marketable fruit weight	January	25.8	7.4
	February	11.8	14.0
	March	14.3	13.3
	Season	21.9	12.1
Total fruit weight	January	37.3	7.4
	February	13.1	14.2
	March	14.5	11.9
	Season	22.5	11.3
Average fruit weight	January	14.1	9.5
	February	7.3	14.9
	March	10.1	10.4
	Season	10.6	7.2
Fruit firmness	91 DAP	6.5	10.7
	99 DAP	10.8	10.0
	106 DAP	14.7	3.8
	112 DAP	13.3	7.8
	119 DAP	23.9	6.4
	133 DAP	10.3	7.0

Table 5-5. Percentages of sums of squares due to general (GCA) and specific combining ability (SCA) in strawberry in Dover, Florida (1995-1996).

Trait		GCA	SCA
Vigor	30 DAP	7.2	2.3
	44 DAP	4.7	5.9
	58 DAP	4.5	6.0
	72 DAP	7.9	5.8
	86 DAP	7.2	4.8
	100 DAP	7.7	3.5
	114 DAP	11.1	3.1
No. of crowns	57 DAP	6.1	4.5
	85 DAP	11.0	2.0
	113 DAP	10.6	3.1
No. of runners	83 DAP	8.0	2.0
	160 DAP	4.7	7.6
Total no. of runners		7.6	2.0
No. of inflorescences	79 DAP	16.8	3.0
	107 DAP	5.1	3.8
	135 DAP	11.9	1.6
Total no. of inflorescences		8.6	2.2
No. of marketable fruit	January	16.7	3.3
	February	13.1	1.7
	March	13.3	1.9
	Season	11.6	2.2
Marketable fruit weight	January	16.4	3.0
	February	9.5	2.1
	March	14.8	1.5
	Season	13.7	1.2
Total fruit weight	January	17.0	3.4
	February	10.8	1.8
	March	13.2	2.0
	Season	13.2	1.9
Average fruit weight	January	7.7	8.5
	February	13.9	8.5
	March	8.1	6.0
	Season	6.7	6.9
Firmness	148 DAP	18.2	4.3
	153 DAP	13.7	2.9

However, combined parental GCA effects in the second cropping season made up a relatively lower percentage of the total sum of squares when compared with the first year, ranging from only 5.1 to 18.2%.

The results in Tables 5-4 and 5-5 strengthen the case for the importance of GCA effects in the sets of parents used in these experiments. Higher GCA values indicate the prevalence of additive genetic effects. Gravois and McNew (1993) attribute 69-89% of the total genetic variation in yield, plant height, panicle number, length and weight, and primary branches in rice to GCA. They conclude that additive gene action played an important role in the expression of these traits, although SCA was also important in some of the traits.

GCA and SCA effects are important parameters in predicting the performance of parents and hybrids. Information on combining ability can be particularly helpful in a strawberry breeding program. Strawberries are an expensive crop to grow so any information or procedure that can make the development of new cultivars more efficient will be an advantage to the breeder.

Simmonds (1979) cautions that combining ability values obtained are relative and will vary depending on the mean of the parent genotypes. When calculating estimates of GCA in a factorial mating design, values obtained for all pairs of parents are arranged in a two-way table and the sums of rows and columns are obtained. The sums of rows and columns are assumed to be equal to each other and to zero. This is a not a sound assumption if the number of parents is small. A diallel crossing pattern may give more reliable estimates.

The sums of squares used to come up with the percentages in Tables 5-4 and 5-5 are in Appendix Tables 1 and 2. Estimates of GCA and SCA for each trait are shown in Appendix Tables 3 to 19. These values were calculated using PROC MIXED in SAS, with block considered a fixed effect and all other effects considered random.

CHAPTER 6
ESTIMATES OF GENETIC PARAMETERS

Estimates of genetic parameters of a plant population are important in designing a breeding program for the improvement of specific traits. Parameters such as genetic variances and heritabilities provide information about the pattern of inheritance of a trait, so that crossing and selection procedures may be planned accordingly. In strawberries, numerous estimates of genetic parameters for quantitative traits have been obtained, but the information is usually applicable only to a specific population and environment. The information obtained in this particular research is important because of the fact that quantitative genetic studies have not been done on the strawberry breeding population at the University of Florida.

The University of Florida breeding program is unique because it is conducted in an environment different from that in which most of the annual system production occurs. The production area in Florida is considered subtropical, while most annual system production occurs in a Mediterranean (California, Spain, and Italy) or temperate marine (Japan) environment. Because the climates in these areas are different from the Florida climate, the growing season also differs. In Florida, the growing season is in late fall to early spring, the time of year when it is too cold to grow strawberries in the more northern latitudes.

The genotypes used as parents to generate the crosses or families and their pedigrees are listed in Table 6-1. The genotypes used as male parents were from the

University of California breeding program, while those used as females were from the University of Florida breeding program. FL90-51 has a common parent with 'Anaheim' and 'Laguna', while FL91-48 has a common parent with 'Cuesta'. These five genotypes are only a few of the total number of genotypes used as parents in this study, but a certain degree of inbreeding is assumed to have occurred in the progenies of crosses that utilized these as parents.

Table 6-1. Pedigree of genotypes used as female and male parents.

Genotype	Pedigree
Female parents	
FL87-236	FL84-3163 x FL83-37
FL89-123	FL82-1452 x FL87-136
FL90-10	FL87-18 x Sweet Charlie
FL90-51	FL83-37 x Irvine
FL91-37	FL87-236 x FL82-1452
FL91-48	FL87-236 x Seascape
FL92-28	FL90-8 x FL90-59
Rosa Linda	FL87-418 x FL87-200
Sweet Charlie	FL80-456 x Pajaro
Male parents	
Anaheim	Irvine x Cal85.92-602
Camarosa	Douglas x Cal85.218-605
Carlsbad	Irvine x Cal85.218-605
Cuesta	Seascape x Cal83.25-2
Laguna	Irvine x Cal85.92-602
Oso Grande	Parker x Cal77.3-603
Selva	Cal70.3-117 x Cal 71.98-605
Sunset	Cal75.121-101 x Cal81.16-604

In the first cropping season, 1994-1995, data were taken on a plot basis except for the number of crowns, which was counted on two plants per plot. The number of runners, the number of fruit, and the weight of fruit per plot were divided by the number of surviving plants to obtain the plot mean. This method of taking data allowed only for the calculation of family heritability and not individual plant heritability. In the 1995-

1996 season, data were taken on individual plants. Both family and individual plant heritability were estimated from these data. Estimates of other genetic parameters, such as variance components and genetic variances, for the different traits measured were also obtained for the two cropping seasons. These genetic parameters were estimated using PROC MIXED in SAS (SAS, 1989-1996), with block considered a fixed effect and all other effects considered random.

Variance Components

In a factorial mating system, variance component estimates can be obtained for the female parents (σ^2_f), male parents (σ^2_m), and the crosses (σ^2_{fm}). Variance components for vegetative and reproductive traits are shown in Tables 6-2 and 6-3. Generally, genotypes designated as females had more variability than those designated as males for the traits evaluated as shown by the variance components for both seasons. This variation may be attributed to the more diverse set of parents of the genotypes used as females than the cultivars used as males. Since the female and male effects were considered random, the genotypes used as parents were assumed to be representative of the whole population of genotypes from which they were obtained. Using a random model, Spangelo et al. (1971) also obtained different estimates of variance components in almost all characters evaluated, and suggest that different degrees of genetic diversity existed between the male and female groups.

No negative estimates of variance were obtained because the statistical program that was used equated all negative values to zero. According to Dudley and Moll (1969), zero values usually indicate that the variances are very small. Spangelo et al. (1971)

Table 6-2. Variance components for vegetative traits, yield and fruit firmness (1994-1995).

Trait		σ^2_f	σ^2_m	σ^2_{fm}
No. of runners	46 DAP[1]	0.064	0.060	0.120
	91 DAP	0.021	0.020	0
Total no. of runners		0.148	0.053	0.191
No. of crowns	92 DAP	0.224	0.070	0.063
Vigor	27 DAP	0.016	0.021	0.090
	42 DAP	0.033	0.015	0.182
	57 DAP	0.082	0.008	0.171
	69 DAP	0.056	0	0.173
No. of marketable fruit	January	0.168	0.063	0
	February	0.404	0.000	0.330
	March	0.847	0.751	1.642
	Season	4.400	1.001	2.211
Marketable fruit weight (g/plant)	January	180.7	63.1	2.3
	February	113.3	57.6	218.6
	March	541.8	453.4	728.2
	Season	2743.5	854.8	1246.7
Total fruit weight (g/plant)	January	200.2	76.6	3.8
	February	138.2	85.8	247.3
	March	672.7	632.1	612.2
	Season	3132.7	1196.0	1147.21
Average fruit weight (g/fruit)	January	3.900	1.471	0.157
	February	0.582	0	1.615
	March	0	0.593	0.258
	Season	0.300	0.345	0
Fruit firmness	91 DAP	0.024	0	0.092
	99 DAP	0.032	0.036	0.070
	106 DAP	0.044	0.042	0.001
	112 DAP	0.083	0.007	0.019
	119 DAP	0.101	0.045	0.013
	133 DAP	0.040	0.046	0.019

[1] Days after planting

Table 6-3. Variance components for vegetative and production traits on an individual plant basis (1995-1996).

Trait		σ^2_f	σ^2_m	σ^2_{fm}
No. of runners	83 DAP[1]	0.139	0.038	0
	160 DAP	0.000	0.001	0.004
Total no. of runners		0.142	0.060	0
No. of crowns	57 DAP	0.069	0.038	0.011
	85 DAP	0.133	0.328	0
	113 DAP	0.342	2.251	0
Vigor	30 DAP	0.024	0.008	0
	44 DAP	0.014	0	0.016
	58 DAP	0.009	0.002	0.022
	72 DAP	0.033	0.024	0.018
	86 DAP	0.028	0.018	0.013
	100 DAP	0.043	0.028	0.010
	114 DAP	0.038	0.062	0.002
No. of inflorescences	79 DAP	0.028	0.021	0.001
	107 DAP	0.011	0.008	0.005
	135 DAP	0.182	0.620	0
Total no. of inflorescences		0.159	0.370	0
No. of marketable fruit	January	0.333	0.255	0.031
	February	0.671	1.315	0
	March	3.832	4.915	0
	Season	7.595	0.867	0
Marketable fruit weight (g/plant)	January	248.2	190.4	16.3
	February	407.2	195.8	0
	March	1252.1	2255.1	0
	Season	3771.7	543.8	0
Total fruit weight (g/plant)	January	273.2	214.4	30.7
	February	515.4	324.2	0
	March	1853.8	2290.8	0
	Season	5251.9	329.8	0
Average fruit weight (g/fruit)	January	5.519	0	0.414
	February	4.804	3.872	4.691
	March	0.094	0.573	0.239
	Season	0.087	0.400	0.438
Fruit firmness	148 DAP	0.166	0	0.044
	153 DAP	0.090	0	0.020

[1] Days after planting

considered all the negative estimates obtained as zero in the calculation of variances used to estimate heritability.

Genetic Variances

Additive (σ^2_{af} and σ^2_{am}) and dominance (σ^2_d) variances were calculated using values obtained for the variance components. Lynch and Walsh (1998) define additive variance as the "genetic variance associated with the average additive effects of alleles", while dominance variance is the "genetic variance associated with dominance effects". The difference between the two is that the additive effect is exhibited when the alleles are transmitted to offspring, whereas the dominance effect is eliminated upon the production of gametes.

Two estimates of additive variance were obtained, one from the female and one from the male components of variance (Tables 6-4 and 6-5). Additive variance for most traits was higher in the female source than in the male. This is particularly true in the first year, when estimates of σ^2_{af} for number of runners 46 DAP, vigor, number of marketable fruit in February, and marketable fruit weight in January were magnitudes higher than σ^2_{am}. It is also interesting to note that estimates for number and weight of marketable fruit, total fruit weight, average fruit weight in January, and fruit firmness are higher in the females than in the males in both cropping seasons. These results show that there is more variability in the female population for the traits of interest, namely high early yield and large, firm fruit.

Estimates of additive variance were usually higher than estimates of dominance variance. It is possible that the additive genetic variance was biased upward. A few of the genotypes used to make the crosses had the same parents. This may have led to some

Table 6-4. Genetic variances for vegetative traits, yield and fruit firmness (1994-1995).

Trait		σ^2_{af}	σ^2_{am}	σ^2_{d}
No. of runners	46 DAP[1]	0.257	0.024	0.478
	91 DAP	0.086	0.080	0
Total no. of runners		0.590	0.213	0.764
No. of crowns	92 DAP	0.896	0.279	0.250
Vigor	27 DAP	0.066	0.084	0.361
	42 DAP	0.131	0.061	0.728
	57 DAP	0.326	0.034	0.685
	69 DAP	0.225	0	0.692
No. of marketable fruit	January	0.673	0.253	0
	February	1.614	0.000	1.319
	March	3.386	3.004	6.566
	Season	17.6	4.0	8.8
Marketable fruit weight (g/plant)	January	722.8	252.4	9.1
	February	453.2	230.5	874.5
	March	2167.3	1813.7	2912.7
	Season	10974.1	3419.1	4986.8
Total fruit weight (g/plant)	January	800.7	306.6	15.1
	February	552.7	343.4	989.3
	March	2690.9	2528.4	2448.8
	Season	12530.7	4784.0	4588.8
Average fruit weight (g/fruit)	January	15.6	5.9	0.630
	February	2.328	0	6.459
	March	0	2.374	1.032
	Season	1.201	1.380	0
Fruit firmness	91 DAP	0.097	0	0.366
	99 DAP	0.129	0.146	0.282
	106 DAP	0.176	0.167	0.031
	112 DAP	0.332	0.026	0.078
	119 DAP	0.403	0.181	0.052
	133 DAP	0.159	0.185	0.075

[1] Days after planting

Table 6-5. Genetic variances for vegetative and production traits on an individual plant basis (1995-1996).

Trait		σ^2_{af}	σ^2_{am}	σ^2_{d}
No. of runners	83 DAP[1]	0.555	0.151	0
	160 DAP	0.000	0.004	0.017
Total no. of runners		0.566	0.241	0
No. of crowns	57 DAP	0.277	0.152	0.043
	85 DAP	0.534	1.311	0
	113 DAP	1.368	9.006	0
Vigor	30 DAP	0.098	0.032	0
	44 DAP	0.056	0	0.066
	58 DAP	0.034	0.007	0.087
	72 DAP	0.131	0.095	0.073
	86 DAP	0.112	0.071	0.052
	100 DAP	0.171	0.110	0.041
	114 DAP	0.154	0.249	0.009
No. of inflorescences	79 DAP	0.110	0.083	0.005
	107 DAP	0.045	0.033	0.021
	135 DAP	0.729	2.481	0
Total no. of inflorescences		0.635	1.478	0
No. of marketable fruit	January	1.333	1.021	0.122
	February	2.683	5.260	0
	March	15.3	19.7	0
	Season	30.4	3.5	0
Marketable fruit weight (g/plant)	January	992.7	761.4	65.3
	February	1628.8	783.2	0
	March	5008.3	9020.4	0
	Season	15086.9	2175.3	0
Total fruit weight (g/plant)	January	1092.6	857.6	122.9
	February	2061.6	1296.9	0
	March	7415.1	9163.4	0
	Season	210007.6	1319.3	0
Average fruit weight (g/fruit)	January	22.075	0	1.655
	February	19.2	15.5	18.8
	March	0.377	2.293	0.957
	Season	0.350	1.582	1.750
Fruit firmness	148 DAP	0.664	0	0.175
	153 DAP	0.360	0	0.079

[1] Days after planting

degree of inbreeding among the progenies used in the experiment. According to Lynch and Walsh (1998), inbreeding generally increases the additive genetic variance by causing interaction among the effects of alleles within the same individual. Genetic variances were estimated with the assumption that there is no epistasis, or interaction among alleles in different loci. The epistatic variance, if present, may therefore have been incorporated into the estimates for σ^2_a and σ^2_d.

Heritability

The two estimates for additive variance made it possible to have two estimates of narrow sense heritability. Narrow-sense heritability, or h^2, is the ratio of the additive genetic variance to phenotypic variance, calculated following Hallauer and Miranda (1981). Its importance lies in the fact that it can be used as a measure of the reliability of predicting the average performance of progenies based on the average performance of the parents (Falconer, 1981).

Estimates of heritability on an entry-mean basis for both seasons are shown in Tables 6-6 and 6-7. Heritability estimates in the female were usually higher than estimates in the male, which is due to the higher diversity in the females. Spangelo et al. (1971) also obtained wide differences between estimates of heritability in male and female groups. They conclude that the male and female parents came from different subpopulations of strawberries grown in North America.

Values for vigor and fruit firmness varied depending on the period of the growing season during which the estimates were taken. Generally, heritability for vigor in the two seasons, and fruit firmness in the first season, increased as the season progressed.

Table 6-6. Heritability of vegetative traits, yield and fruit firmness (1994-1995).

Trait		h^2_f	h^2_m
No. of runners	46 DAP[1]	0.74	0.18
	91 DAP	0.92	0.90
Total no. of runners		0.80	0.54
No. of crowns	92 DAP	0.91	0.72
Vigor	27 DAP	0.50	0.51
	42 DAP	0.50	0.28
	57 DAP	0.73	0.19
	69 DAP	0.64	-
No. of marketable fruit	January	0.97	0.92
	February	0.84	0.00
	March	0.70	0.63
	Season	0.90	0.62
Marketable fruit weight (g/plant)	January	0.98	0.92
	February	0.70	0.50
	March	0.76	0.69
	Season	0.90	0.71
Total fruit weight (g/plant)	January	0.98	0.93
	February	0.72	0.57
	March	0.80	0.76
	Season	0.92	0.78
Average fruit weight (g/fruit)	January	0.94	0.83
	February	0.60	-
	March	-	0.84
	Season	0.87	0.86
Fruit firmness	91 DAP	0.57	-
	99 DAP	0.68	0.67
	106 DAP	0.93	0.91
	112 DAP	0.94	0.50
	119 DAP	0.96	0.91
	133 DAP	0.87	0.87

[1] Days after planting

Table 6-7. Heritability of vegetative and production traits on an entry-mean (family) basis (1995-1996).

Trait		h^2_f	h^2_m
No. of runners	83 DAP[1]	0.86	0.69
	160 DAP	0.05	0.46
Total no. of runners		0.84	0.77
No. of crowns	57 DAP	0.74	0.70
	85 DAP	0.79	0.93
	113 DAP	0.66	0.95
Vigor	30 DAP	0.83	0.70
	44 DAP	0.53	0
	58 DAP	0.39	0.17
	72 DAP	0.70	0.72
	86 DAP	0.71	0.70
	100 DAP	0.78	0.77
	114 DAP	0.80	0.91
No. of inflorescences	79 DAP	0.91	0.92
	107 DAP	0.58	0.61
	135 DAP	0.78	0.95
Total no. of inflorescences		0.76	0.92
No. of marketable fruit	January	0.90	0.92
	February	0.83	0.94
	March	0.84	0.91
	Season	0.90	0.60
Marketable fruit weight (g/plant)	January	0.91	0.92
	February	0.85	0.80
	March	0.84	0.94
	Season	0.92	0.71
Total fruit weight (g/plant)	January	0.90	0.91
	February	0.86	0.86
	March	0.86	0.92
	Season	0.92	0.54
Average fruit weight (g/fruit)	January	0.88	-
	February	0.73	0.77
	March	0.36	0.84
	Season	0.29	0.74
Fruit firmness	148 DAP	0.90	-
	153 DAP	0.90	-

[1] Days after planting

Heritability estimates on an individual plant basis for the cropping season 1995-1996 are in Table 6-8. Since selection in strawberries is usually done on individual plants, heritabilities calculated based on individual plant observations are more meaningful. Estimates obtained for traits measured over time showed variation as the season progressed. Heritability for vigor was higher during the first month and toward the last months than in the middle of the growing season. The differences in heritability over the growing period make it possible to select for high vigor at a time when heritability is expected to be highest and the differences among plants most noticeable.

The heritability for number of inflorescences was highest 79 DAP. This corresponds to the time when most plants start producing inflorescences. As mentioned in Chapter 4, the number of inflorescences 79 DAP was found to be significantly correlated with number and weight of marketable fruit and total fruit weight in January. The UF breeding program does not currently consider data on inflorescences, but it might be worth the effort to count inflorescences early in the season when selecting for high early yield.

In terms of yield, the heritability for number and weight of marketable fruit, total fruit weight, and average fruit size was higher in January than in February and March in the females. High early yield is one of the objectives of the breeding program. The higher heritability of January yield will make it possible to improve this trait using parental genotypes from the UF population, from which the female parents came.

Heritability estimates for fruit firmness rated 148 and 153 DAP are very high. Hansche et al. (1968) obtained an estimate of 0.46, which was considered moderately high. The high estimates indicate that the trait can be improved through breeding. While

Table 6-8. Heritability of vegetative and production traits on an individual plant basis (1995-1996).

Trait		h^2_f	h^2_m
No. of runners	83 DAP[1]	0.25	0.07
	160 DAP	0.01	0.07
Total no. of runners		0.23	0.10
No. of crowns	57 DAP	0.15	0.08
	85 DAP	0.16	0.39
	113 DAP	0.08	0.55
Vigor	30 DAP	0.22	0.07
	44 DAP	0.08	-
	58 DAP	0.05	0.01
	72 DAP	0.15	0.11
	86 DAP	0.16	0.10
	100 DAP	0.20	0.13
	114 DAP	0.19	0.30
No. of inflorescences	79 DAP	0.45	0.34
	107 DAP	0.08	0.06
	135 DAP	0.15	0.50
Total no. of inflorescences		0.14	0.32
No. of marketable fruit	January	0.47	0.36
	February	0.21	0.41
	March	0.24	0.30
	Season	0.39	0.05
Marketable fruit weight (g/fruit)	January	0.46	0.35
	February	0.25	0.12
	March	0.23	0.41
	Season	0.48	0.07
Total fruit weight (g/plant)	January	0.47	0.37
	February	0.28	0.18
	March	0.25	0.31
	Season	0.53	0.03
Average fruit weight (g/fruit)	January	0.37	-
	February	0.32	0.26
	March	0.04	0.25
	Season	0.04	0.17
Fruit firmness	148 DAP	0.84	-
	153 DAP	0.65	-

[1] Days after planting

no estimates were obtained from the male for fruit firmness in 1995-1996, family heritability estimates in 1994-1995 (Table 6-6) show that parent genotypes from both the UF and UC populations may be sources of variation for the trait.

The traits of interest, i. e., high early (January) yield, and large and firm fruit, appear to have moderately to very high heritability. In addition to these traits, other traits that may be considered important include vigor and number of inflorescences. These traits with high heritability may be improved by recurrent selection. High values for additive genetic variance, which lead to high heritability estimates, permit the prediction of average performance of the progeny from that of the parents. The improvement made in these traits during selection is expected to accumulate over successive generations (Shaw et al., 1987).

For traits where heritability estimates varied depending on the period of the growing season, such as vigor and monthly yield, response to selection may be improved by selecting for these traits during the period when differences among progenies are expected to be greatest.

CHAPTER 7
GENETIC PARAMETERS FROM PART AND COMPLETE RECORDS

Shortening the cultivar development period is one way of increasing efficiency, which is always a goal in breeding programs. Part-record selection, a version of indirect selection, can be used to achieve this goal. Part-record selection is selection based on performance during a portion of the production cycle (Shaw, 1989). Part-record selection in both animals and perennial trees usually has been done to shorten the generation interval with minimal reduction of the genetic gain per generation. In strawberries, Shaw (1989) estimated genetic parameters using part-records and obtained maximum narrow sense heritability estimates after eight to nine weeks of harvest. These estimates were higher than narrow sense heritability for whole season yield. Based on a comparison of estimates of genetic gain from part-records selection and direct selection, Shaw suggested that cumulative or alternate-weeks part-record selection can be used in place of direct selection to improve yield and fruit size in strawberries. However, the magnitude of genetic parameters will vary depending on the traits being measured and the program design.

In the present study, genetic parameters for yield were estimated using part-records from data taken in cropping season 1995-1996. Data from odd weeks collected from the third to the nineteenth week of harvest were used. The objective was to determine if the collection of yield data could be reduced by one-half without significantly changing the estimates of heritability and genetic variances. If estimates derived from the different data sets are similar, then it might be reasonable to conclude that twice as many genotypes could be evaluated without increasing the workload. Data on a second set of plants could be collected during the even weeks.

The analyses were performed using PROC MIXED in SAS (SAS Institute, 1989-1996), with female and male effects random and block effect fixed. Variance components for the female, the male, and the female x male effects were obtained from the yield data and used to calculate additive and dominance variances and narrow sense heritability. The genetic parameters estimated from part-records were compared with those obtained using complete records. Genetic parameters for all traits from complete records were discussed in Chapter 6, but those for yield are included in this chapter for ease of discussion.

Variance components from part-records are in Table 7-1. The estimates are generally smaller than the variance components from complete records, which are shown in Table 7-2. The differences were considerable in some instances. For example, variance for the female in January marketable fruit weight using part-records was only about a fourth of the variance for the female using complete records. Variance components using part-records were higher for average fruit weight in the female for February and March, and in the male for March and the whole season. As in Chapter 6, no negative values were obtained because the statistical program equated all negative values to zero. Zero values usually indicate that the variances are very small (Dudley and Moll, 1969).

Table 7-1. Variance components for monthly and total season yield based on part-records, Dover, Florida (1995-1996).

Trait		σ^2_f	σ^2_m	σ^2_{fm}
No. of marketable fruit	January	0.11	0.11	0.01
	February	0.16	0.19	0
	March	0.73	0.94	0
	Season	1.99	0.12	0
Marketable fruit weight (g/plant)	January	67.06	88.11	13.59
	February	197.60	5.66	0
	March	189.08	467.54	0
	Season	1027.20	85.86	0
Total fruit weight (g/plant)	January	68.24	92.03	24.18
	February	210.60	27.31	0
	March	314.24	402.62	0
	Season	1336.64	9.82	0
Average fruit weight (g/fruit)	January	2.10	0	0
	February	5.77	2.60	4.16
	March	0.22	1.51	0
	Season	0.01	0.87	0.42

Table 7-2. Variance components for monthly and total season yield based on complete records, Dover, Florida (1995-1996).

Trait		σ^2_f	σ^2_m	σ^2_{fm}
No. of marketable fruit	January	0.33	0.26	0.03
	February	0.67	1.32	0
	March	3.83	4.92	0
	Season	7.60	0.87	0
Marketable fruit weight (g/plant)	January	248.17	190.36	16.33
	February	407.21	195.79	0
	March	1252.08	2255.09	0
	Season	3771.72	543.83	0
Total fruit weight (g/plant)	January	273.15	214.40	30.73
	February	515.39	324.21	0
	March	1853.76	2290.84	0
	Season	5251.89	329.82	0
Average fruit weight (g/fruit)	January	5.52	0	0.41
	February	4.80	3.87	4.69
	March	0.09	0.57	0.24
	Season	0.09	0.40	0.44

The trend in genetic variances was similar to that in variance components. Estimates of additive and dominance variances from part-records (Table 7-3) were generally smaller than estimates from complete records (Table 7-4). However, additive variance was still more important than dominance variance in all measures of yield, regardless of whether partial or complete data was used.

Narrow sense heritability of the different measures of monthly and whole season yield from part-records is shown in Table 7-5. Except for slightly higher values for marketable and average fruit weight in February in the female, and season average fruit weight in the male, all other estimates were lower using part-records than complete records (Table 7-6). Heritability estimates in the female in January yield using part-records were half of estimates using complete records. In the male, estimates for February yield decreased considerably. However, heritability from part-records for number and weight of marketable fruit, total fruit weight, and average fruit size was generally higher in January and February than in March in the females. There was relatively little change in estimates of heritability for March and whole season yield.

In spite of the lower estimates using part-records, the estimate of heritability for January yield shows the same relationship relative to heritability for March yield as in complete records. Heritability for January yield is still generally higher than heritability for March yield. However, the slight decrease in heritability for whole season yield and the reduction by almost half of heritability for January and February yield using part-records may lead one to inaccurately conclude that it will be better to measure whole season yield rather than partial season yield. The type of part-records used in this study, i. e., yield data on odd weeks, still provides useful information. The higher heritabilities

Table 7-3. Genetic variances for monthly and total season yield based on part-records, Dover, Florida (1995-1996).

Trait		σ^2_{af}	σ^2_{am}	σ^2_{d}
No. of marketable fruit	January	0.45	0.43	0.06
	February	0.63	0.78	0
	March	2.92	3.77	0
	Season	7.96	0.47	0
Marketable fruit weight (g/plant)	January	268.22	352.44	54.37
	February	790.42	22.62	0
	March	756.31	1870.16	0
	Season	4108.80	343.44	0
Total fruit weight (g/plant)	January	272.96	368.12	96.73
	February	842.38	109.23	0
	March	1256.95	1610.46	0
	Season	5346.57	39.30	0
Average fruit weight (g/fruit)	January	8.42	0	0
	February	23.08	10.40	16.66
	March	0.90	6.06	0
	Season	0.02	3.47	1.69

Table 7-4. Genetic variances for monthly and total season yield based on complete records, Dover, Florida (1995-1996).

Trait		σ^2_{af}	σ^2_{am}	σ^2_{d}
No. of marketable fruit	January	1.33	1.02	0.12
	February	2.68	5.26	0
	March	15.33	19.66	0
	Season	30.38	3.47	0
Marketable fruit weight (g/plant)	January	992.67	761.45	65.31
	February	1628.85	783.17	0
	March	5008.33	9020.36	0
	Season	15086.86	2175.32	0
Total fruit weight (g/plant)	January	1092.58	857.58	122.91
	February	2061.55	1296.86	0
	March	7415.05	9163.36	0
	Season	210007.56	1319.29	0
Average fruit weight (g/fruit)	January	22.08	0	1.66
	February	19.22	15.49	18.77
	March	0.38	2.29	0.96
	Season	0.35	1.58	1.75

Table 7-5. Individual heritability of monthly and total season yield based on part-records, Dover, Florida (1995-1996).

Trait		h^2_f	h^2_m
No. of marketable fruit	January	0.28	0.27
	February	0.12	0.15
	March	0.17	0.22
	Season	0.34	0.02
Marketable fruit weight (g/plant)	January	0.23	0.30
	February	0.27	0.01
	March	0.13	0.32
	Season	0.40	0.03
Total fruit weight (g/plant)	January	0.21	0.28
	February	0.26	0.03
	March	0.19	0.24
	Season	0.45	0.00
Average fruit weight (g/fruit)	January	0.14	-
	February	0.34	0.15
	March	0.04	0.25
	Season	0.00	0.19

Table 7-6. Individual heritability of monthly and total season yield based on complete records, Dover, Florida (1995-1996).

Trait		h^2_f	h^2_m
No. of marketable fruit	January	0.47	0.36
	February	0.21	0.41
	March	0.24	0.30
	Season	0.39	0.05
Marketable fruit weight (g/plant)	January	0.46	0.35
	February	0.25	0.12
	March	0.23	0.41
	Season	0.48	0.07
Total fruit weight (g/plant)	January	0.47	0.37
	February	0.28	0.18
	March	0.25	0.31
	Season	0.53	0.03
Average fruit weight (g/fruit)	January	0.37	-
	February	0.32	0.26
	March	0.04	0.25
	Season	0.04	0.17

of January and February yield over March yield when part-records were used indicates that variation exists among the female parents in terms of high early yield. It will be possible to improve early yield using parental genotypes from the UF population, from which the female parents came.

CHAPTER 8

GENETIC CORRELATION

Phenotypic correlation between traits was discussed in Chapter 4. Phenotypic correlation includes both environmental and genetic correlations. In this chapter, estimates of genetic correlation between traits will be considered. Genetic correlation is the correlation of breeding values (Falconer, 1989). It may be more useful to plant breeders because it is separated from any environmental effect and may, therefore, give an indication of the degree to which a pair of traits may be inherited.

According to Falconer (1989), there are three main reasons for studying correlations between traits. First, it is known that pleiotropy, where a gene affects different traits, is common among major genes, but as yet has been little studied in quantitative traits. The second reason involves the effect of the improvement of one trait on a second trait. For example, the improvement of the first trait may cause a decline in a second trait. The third reason involves natural selection and will not have an important bearing on this study. The genetic properties of a quantitative trait in a natural population are determined by the relationship between that trait and fitness. The fitness of an individual refers to the contribution which that individual makes to the next generation in terms of the progeny that survive and pass on the genes for the trait.

Using estimates of genetic correlations, relationships among traits may be inferred, making it possible to make decisions regarding which traits to include in a breeding program. Such relationships can also show if two traits are governed by the same physiological mechanism. Genetic correlation also helps in indirect selection, where selection is done on a trait that is easier or faster to measure to improve another trait of interest. Finally, estimates of genetic correlation can be used to develop weights necessary to construct a selection index. Hallauer and Miranda (1981) discuss some of these applications in detail.

Data from the 1995-1996 cropping season were subjected to an analysis of covariance using SAS (SAS Institute 1989-1996). Two estimates of genetic correlation were obtained for each pair of traits, one for the females and one for the males. This is possible in a factorial mating design because there are two main effects or sources of variation, the female and the male.

Genetic correlations among number of crowns, number of runners and vigor (Table 8-1) follow the phenotypic correlation trend described in Chapter 4. Number of runners is generally negatively correlated with number of crowns and vigor. This has important implications for both fruit and runner plant production. A restriction in runner production accompanied by an increase in vigor due to more crown production may increase potential fruit production. On the other hand, a reduction in the number of runners is not acceptable when multiplication of the genotype is desired. Since strawberry is clonally propagated through daughter or runner plants, a low number of runners will make multiplication of a clone more difficult. This study was done during the regular fruit production season in late winter and early spring. It is not known how each genotype will respond in terms of runner production during the normal season for runner plant production, which is during the summer.

Table 8-1. Genetic correlation[1] among vegetative traits in strawberries grown at Dover, Florida (1995-1996).

Traits	No. of crowns			No. of runners	
	57 DAP	85 DAP	113 DAP	83 DAP	Total
No. of runners	0.13	0.01			
83 DAP	*-0.54*	*-0.57*			
Total no. of	0.04	-0.03	-0.77		
runners	*-0.56*	*-0.60*	*-0.13*		
Vigor 30 DAP	0.45	0.11	-0.00	-0.13	-0.28
	0.26	*0.40*	*-0.18*	-	-
Vigor 44 DAP	-	0.70	0.33	-0.02	-0.34
	-	-	-	-	-
Vigor 58 DAP	-	0.99	0.45	-0.01	-0.30
	-	-	-	*-0.69*	*-0.72*
Vigor 72 DAP	0.86	-	0.59	0.08	-0.08
	-	-	-	*-0.38*	*-0.35*
Vigor 86 DAP	0.90	-	0.60	0.01	-0.09
	-	-	-	*-0.37*	*-0.23*
Vigor 100 DAP	0.50	0.95	0.61	-0.20	-0.17
	-	-	*0.87*	*-0.27*	*-0.27*
Vigor 114 DAP	0.32	0.92	0.97	-0.22	-0.26
	-	*0.87*	*-0.93*	*-0.14*	*-0.05*

[1] Numbers in italics refer to estimates for males.

The number of crowns and vigor generally have high positive genetic correlation. A large phenotypic correlation between the two was expected and obtained because it is logical that more crowns would make a plant look more vigorous during evaluation. However, the individual heritability estimates (Table 6-8) for these two traits were relatively low, so the high genetic correlation between them was not expected. Generally, traits with low heritabilities are affected to a large extent by the environment. However, traits with high heritabilities usually have more important genetic correlation (Falconer, 1989).

Correlation coefficients for pairs of vegetative and reproductive traits are listed in Table 8-2. Vigor and number of inflorescences were generally positively correlated, with coefficients usually higher for the female than for the male. However, the number of crowns 57 DAP and the number of inflorescences 79 and 107 DAP generally had very low correlation. The value was even negative for number of crowns 85 DAP and number of inflorescences 79 DAP for the female. While higher early plant vigor may promote early flowering, it appears that more crowns early in the season do not necessarily lead to more inflorescences during that period of the growing season. However, the high correlation between total number of inflorescences and number of crowns suggests that flowering is still very dependent on the final number of potential sites from which the inflorescences will develop. These sites are determined by the number of branch crowns formed, because each branch crown can produce only one inflorescence.

Number of runners was generally positively correlated with number of inflorescences 79 and 107 DAP. The correlation coefficient between number of runners 83 DAP and number of inflorescences 107 DAP is very high in the female. This positive correlation is difficult to explain because it is unexpected. Previous results suggest that greater runner production inhibits inflorescence production. It is possible that a physiological shift from vegetative to reproductive growth occurred after the runners were counted 83 DAP, which resulted in higher inflorescence production 107 DAP. The mean number of inflorescences increased from 0.38 per plant 79 DAP to 0.66 per plant 107 DAP.

The negative correlation between number of runners and number of inflorescences 135 DAP and total number of inflorescences was the expected response. This negative

Table 8-2. Genetic correlation[1] between vegetative and reproductive traits in strawberries (Dover, Florida, 1995-1996).

Trait	No. of inflorescences				January yield		
	79DAP	107DAP	135DAP	Total	Number	Weight (g)	Ave. wt. (g)
Crowns	0.08	0.06	0.28	0.39	-0.08	0.07	0.28
57DAP	-	*-0.16*	-	-	-	-	-
Crowns	-0.40	0.72	0.86	0.92	-0.24	0.20	0.56
85DAP	-	*0.00*	*0.82*	*0.84*	*-0.93*	*-0.92*	-
Crowns		-0.20	0.40	0.18			
113DAP		*-0.54*	*0.99*	*0.99*			
Runners	-0.05	0.94	-0.20	0.02	-0.09	-0.10	-0.39
83DAP	*0.24*	*0.11*	*-0.16*	*-0.14*	*-0.01*	*-0.09*	-
Total	-0.15	0.93	-0.18	-0.02			
runners	*0.25*	*0.14*	*-0.11*	*-0.07*			
Vigor	0.85	-0.02	-0.63	-0.29	0.78	0.77	0.26
30DAP	*-0.21*	*0.51*	*-0.10*	*0.10*	*0.20*	-	-
Vigor	0.83	0.17	-0.13	0.27	0.71	0.89	-0.80
44DAP	-	-	-	-	-	-	-
Vigor	0.78	-	0.42	0.90	0.88	-0.38	-
58DAP	-	-	-	-	-	-	-
Vigor	0.03	0.79	0.56	0.78	0.19	0.28	0.19
72DAP	-	*0.05*	-	-	-	-	-
Vigor	-0.06	0.78	0.58	0.77	0.08	0.22	0.43
86DAP	-	*0.27*	-	-	-	-	-
Vigor	-0.08	0.43	0.36	0.42	0.09	0.20	0.60
100DAP	-	*0.11*	*0.94*	*0.97*	-	-	-
Vigor	-0.52	0.54	0.59	0.58	-0.47	-0.40	0.51
114DAP	-	*-0.14*	*0.97*	*0.99*	-	*-0.90*	-

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[1] Numbers in italics refer to estimates for males.

Table 8-2. Continued.

Trait	February yield			March yield			Season yield		
	Number	Weight (g)	Ave. wt. (g)	Number	Weight (g)	Ave. wt. (g)	Number	Weight (g)	Ave. wt. (g)
Crowns	0.17	0.46	-	0.74	0.83	0.62	0.61	0.68	-
57DAP	-	-	-	*0.67*	*0.81*	*0.86*	*-0.65*	*0.06*	*0.69*
Crowns	0.12	0.46	-	0.87	0.90	-0.01	0.65	0.68	0.79
85DAP	*-0.70*	*-0.87*	*0.62*	*0.36*	*0.35*	*0.03*	*-0.55*	*-0.33*	*-0.17*
Crowns	-0.36	-0.30	0.67	0.12	-	0.57	-0.02	-	-0.12
113DAP	-	*-0.86*	*0.58*	*0.75*	-	*0.64*	*-0.01*	-	*0.55*
Runners	0.36	0.67	0.28	0.63	0.62	-0.20	0.52	0.53	-
83DAP	*-0.00*	*0.15*	*-0.47*	*0.68*	*0.54*	*0.25*	-	-	*0.11*
Total							0.39	0.07	0.91
runners							-	-	*0.04*
Vigor	-	-	-0.40	0.48	-	0.01	0.82	-	0.97
30DAP	*0.43*	*-0.67*	*-0.86*	*-0.62*	-	*-0.93*	-	-	*-1.00*
Vigor	-	0.96	0.00	0.76	0.78	0.35	-	-	-
44DAP	-	-	-	-	-	-	-	-	-
Vigor	-	0.13	-0.02	0.45	-	-0.41	0.95	-	0.96
58DAP	-	-	-	-	-	-	*0.21*	-	*0.89*
Vigor	0.52	0.78	0.92	0.91	0.90	-0.78	0.84	0.84	0.12
72DAP	-	-	*0.54*	*0.72*	*0.73*	*0.12*	*-0.41*	*-0.08*	*-0.22*
Vigor	0.43	0.71	0.93	0.82	0.82	-0.78	0.71	0.72	0.06
86DAP	-	-	*0.54*	*0.73*	*0.72*	*0.12*	*-0.33*	*-0.09*	*-0.22*
Vigor	0.30	0.48	0.58	0.52	0.47	-	0.41	0.39	-0.92
100DAP	*-0.88*	-	*0.44*	*0.61*	*0.59*	*0.16*	*-0.34*	*-0.16*	*-0.15*
Vigor	0.07	0.29	0.81	0.54	0.51	-0.82	0.33	0.31	-0.67
114DAP	*-0.99*	-	*0.86*	*0.81*	*0.80*	*0.45*	*0.05*	*0.25*	*0.22*

[†] Numbers in italics refer to estimates for males.

correlation suggests that there might be competition for assimilates going on between vegetative (runner) and reproductive (flower) growth. Number of runners was also negatively correlated with January yield, which was expected, because production of more vegetative plant parts would have interfered with fruit production. Runners were counted twice during the season, but most of the runners were produced before the first count, which was taken on January 15. Any negative effect that runner production would have should therefore be on early inflorescence and fruit production. The generally positive correlation of number of runners with February, March, and total yield is difficult to explain, given the fact that there was a negative correlation between number of runners and number of inflorescences 135 DAP and for the season.

Vigor was generally positively correlated with monthly number and weight of marketable fruit. Vigor 30 and 44 DAP showed very high genetic correlation with the number and weight of marketable fruit in January in the female. This is a good indication that high early vigor will tend to promote high early yield. High correlation coefficients were also obtained between vigor 44, 72, and 86 DAP, and marketable fruit weight in February. Similarly, there was a high correlation between the vigor ratings later in the season and March yield. These results suggest that plant vigor in the period before fruit production can be an important indication of the amount of fruit that will be produced for that period.

Early vigor and average fruit weight had a relatively low and sometimes negative correlation. However, later vigor had a high correlation with average fruit weight in January and February, but not in March. This seems to suggest that vigor had an effect on fruit size that was the opposite of its effect on number and weight of marketable fruit.

A more vigorous plant would tend to produce more fruit, resulting in heavier total fruit weight, but the fruits would have smaller size. Vigor was generally positively correlated with season number and weight of fruit, but negatively correlated with average fruit weight. This relationship supports the earlier findings on the effects of high vigor on these different measures of yield.

Correlation coefficients for number of inflorescences and the measures of yield in the different months are in Table 8-3. Number of inflorescences 79 DAP and number and weight of marketable fruit in January and February showed high positive correlation. Data on number of inflorescences 79 DAP were taken on January 11, and consist of all inflorescences produced from planting until that date. With the exception of inflorescences produced during the first part of January, the rest were produced in December. As mentioned in Chapter 6, inflorescence data are currently not considered in the UF breeding program. The high correlation is significant, because the number of inflorescences can be an indication of January yield and can be used to predict it. Furthermore, the moderately high narrow sense heritability of 0.45 for number of inflorescences 79 DAP (Table 6-8) indicates that offspring selected on the basis of high early inflorescence number are likely to possess genes for this trait.

Number of inflorescences 107 and 135 DAP and total number of inflorescences were negatively correlated with January yield. One explanation for this is that early fruit production will hinder production of more inflorescences later in the season. Perhaps plants that reach reproductive maturity early are not able to maintain high fruit production over the entire season. It seems that increasing January yield may depress February and

March yield, and therefore total season yield. The positive correlation between March yield and total number of inflorescences supports this suggestion.

In an attempt to determine which has a more important effect on marketable fruit weight, a correlation analysis was performed between this trait and number of marketable fruit and average fruit weight. Generally, a high correlation was obtained between number of fruit in each month and marketable fruit weight (Table 8-4).

Table 8-3. Genetic correlation among number of inflorescences and fruit yield in strawberries grown at Dover, Florida (1995-1996).

Trait	No. of inflorescences			
	79 DAP	107 DAP	135 DAP	Total
No. of fruit in January	0.84	-0.33	-0.43	-0.09
	0.96	*-0.11*	-	-
Wt. of fruit in January	0.89	-0.44	-0.66	-0.45
	0.95	*0.42*	*-0.91*	*-0.97*
Ave. fruit wt. in January	-0.13	0.40	-0.61	-0.64
	-	-	-	-
No. of fruit in February	0.66	0.56	-0.28	0.14
	0.80	*0.66*	-	*-0.03*
Wt. of fruit in February	0.31	-	-	-
	0.96	*0.54*	*-0.84*	*-0.77*
Ave. fruit wt. in February	-0.69	-	0.98	-
	-0.35	*-0.08*	*0.81*	-
No. of fruit in March	-0.16	-	0.40	0.69
	-0.67	*-0.46*	*0.80*	*0.82*
Wt. of fruit in March	-0.15	-	-	-
	-0.60	*-0.73*	*0.95*	*0.98*
Ave. fruit wt. in March	0.47	-0.75	0.35	0.26
	-0.16	-	*0.75*	*0.74*
No. of fruit	0.23	-	0.17	0.56
	-0.06	*-0.23*	*0.12*	*0.13*
Wt. of fruit	0.22	-	-	-
	-0.07	-	-	-
Ave. fruit wt.	0.64	-	0.58	-
	0.12	-	*0.63*	*0.62*

[1] Numbers in italics refer to estimates for males.

Table 8-4. Genetic correlation among monthly measures of fruit yield in strawberries grown in Dover, Florida (1995-1996).

Trait	Marketable fruit weight			
	January	February	March	Season
No. of marketable fruit in January	0.99			0.45
	-			*-0.41*
Ave. wt. in January	-			-
	-			-
No. of marketable fruit in February		0.90		0.85
		-		*-0.80*
Ave. wt. in February		0.51		-
		-		-
No. of marketable fruit in March			-	0.93
			0.98	*0.83*
Ave. wt. in March			-	-
			0.98	*-0.30*

[1] Numbers in italics refer to estimates for males.

Number of fruit in each month had a high positive correlation with marketable fruit weight during the same month. This indicates that marketable fruit weight may be improved by selecting for more fruit. No estimates could be obtained for the relationship between average fruit weight and marketable weight, so it can not be ascertained whether number of fruit has more influence on marketable weight than average fruit weight. Results of the phenotypic correlation in Table 4-4 in Chapter 4, however, showed negative or very low correlation between average fruit weight and marketable fruit weight within the same month. Based on this, it may be reasonable to assume that the genetic correlation between marketable weight and fruit size is not as important as the correlation between marketable weight and number of fruit.

Number of fruit in each month showed a positive correlation with season marketable fruit weight in the female, indicating that more fruits would tend to increase the total marketable fruit weight. The correlation coefficient was lowest in January and increased in February and March, suggesting that January yield had the smallest contribution to total marketable yield. The same results were obtained in phenotypic correlation (Table 4-4). While the overall result of increasing January yield may be a reduction in total season yield, the higher price of fruit in January may offset any loss in profit due to the lower season yield.

The estimates of genetic correlation, together with the heritability estimates, will be very helpful in making decisions regarding which traits to measure. Based on the results, it appears that the number of inflorescences early in the season can be a good indicator of early yield and may be used to predict January yield.

Some of the relationships are confusing, but may be explained by the fact that genetic correlations have inherently large errors (Hallauer and Miranda, 1981). While important information can be obtained from just knowing the sign, i. e., "+" or "-", of a correlation coefficient, completely clean estimates of genetic correlation are not possible because the causal sources of covariance are biased in some instances (Lynch and Walsh, 1998). Furthermore, genetic correlations are influenced by gene frequencies to a large extent so that they may differ considerably in different populations (Falconer, 1989). Estimates of genetic correlations among females and males in this study often showed opposite signs. The genotypes used as female and as male parents come from different populations that were shown to have different genetic characteristics in Chapter 6.

CHAPTER 9
NURSERY SELECTION

Most of the fresh strawberries available in the market during the winter and early spring come from Florida. The predominantly mild climate in this southernmost state makes winter production feasible. However, most of the available cultivars were developed in and are more suited to California. Therefore, there is an ongoing effort to develop new and better cultivars for the subtropical conditions in Florida.

Cultivar development at the University of Florida Gulf Coast Research and Education Center-Dover usually takes six years from the time the hybrid seeds are produced to the time a clone is multiplied for distribution to growers. Hybrid seedlings are grown in a nursery in the summer of the first year for runner plant production. Two runner or daughter plants are taken from each seedling and planted in the fruiting field in the fall. Plants that perform well are selected and advanced to more trials.

It may be feasible to bypass the two-plant evaluation and advance a clone to a 10-plant yield trial in the field, thus shortening the breeding cycle by a year. This would occur if genotypes that will perform well in the fruiting field could be selected in the nursery. An experiment was conducted to see if it is possible to predict which genotypes in the nursery will have the highest early season fruit yield.

Seedlings from 24 families generated by crossing six genotypes designated as females and four genotypes designated as males were planted in the summer nursery in

1995. Seedling plants were selected about two months after transplanting. Details about the selection procedure are described in Chapter 3 (Materials and Methods). Data on general vigor and number of crowns and runners were taken in the nursery on selected and randomly picked seedling plants to determine if there were measurable differences between them. Analysis of variance was performed on the data, with set (selected or randomly picked) considered fixed and female and male effects random.

Seedling plants from the two sets differed significantly for the three traits evaluated (Table 9-1), indicating that selection had an effect on these traits. Female effects were significant for vigor and number of runners, while male effects were significant only for number of runners. This indicates that there was variation among the genotypes used as females and as males for the traits mentioned. Family, or female x male, effect was significant for all traits evaluated, indicating that there was variation in vigor, and number of crowns and runners among seedling plants from different families.

Table 9-1. Mean squares for three traits measured on selected and randomly picked seedlings from 24 families in the nursery at Dover, Florida (1995).

Source	Vigor	No. of crowns	No. of runners
Set (S)	172.71 **	1.85 *	82.55 **
Female (F)	11.18 *	2.40 ns	73.91 *
Male (M)	2.33 ns	0.72 ns	67.41 *
F x M	2.57 **	0.91 **	19.49 **
S x F x M	0.91 ns	0.40 ns	15.54 **

*, ** Significant at $P = 0.05$ and 0.01, respectively.

Means of selected and randomly picked seedling plants for vigor rating, number of runners, and number of crowns were compared. The selected plants were more vigorous and had more crowns and runners than the randomly picked seedlings

(Table 9-2). The increased number of crowns and runners could have contributed to more vigorous looking plants. Vigor and number of crowns and runners have been shown to have positive phenotypic (Chapter 4) and genetic correlation (Chapter 8). Vigor can be an important criterion in selecting for strawberry seedlings in the nursery. Rating can be done quickly by evaluating a plant relative to other plants using visual inspection. In this study, the vigor ratings used were from 1 to 5, with 1 being 'least vigorous' and 5, 'most vigorous'.

Table 9-2. Vegetative attributes[1] of selected and randomly picked seedlings from 24 families in the nursery at Dover, Florida (1995).

Trait	Selected	Randomly picked
Vigor	3.66 a	2.81 b
No. of crowns	1.27 a	1.18 b
No. of runners	8.87 a	8.27 b

[1] Means in a row followed by different letters are significantly different at $P = 0.05$.

One daughter plant from each of the selected and randomly picked seedling plants were grown in the fruiting field the following fall. These plants were evaluated for vegetative and production traits. Data were analyzed as described for nursery data. Results of the ANOVA are shown in Table 9-3.

Between sets, differences were obtained for vigor, number of inflorescences 79 DAP, and number and weight of marketable fruit and total fruit weight in January, February, and for the whole season. It is interesting to note that there was no significant difference between sets for all measures of March yield. Among female and male effects, there was significant variation in most traits except vigor, number of runners 160 DAP and average fruit weight in March and for the season in the female, and number of

Table 9-3. Results of the ANOVA for traits measured on plants from selected and randomly picked seedlings in the fruiting field at Dover, Florida (1995-1996).

Trait		Set (S)	Female (F)	Male (M)	F x M
No. of runners	83 DAP	4.50 ns	21.03**	16.13**	0.87 ns
	160 DAP	0.02 ns	0.07 ns	0.28 *	0.08 *
Total no. of runners		6.10 ns	18.85**	19.31**	1.12 ns
No. of crowns	57 DAP	4.51 ns	10.48 *	11.19 *	2.94 ns
	85 DAP	3.71 ns	15.00 *	56.65**	4.24 ns
	113 DAP	24.71 ns	55.82 *	226.86**	17.86 ns
Vigor	30 DAP	15.35**	4.33**	1.86 *	0.48 ns
	44 DAP	4.59**	2.74 ns	1.56 ns	1.28 *
	58 DAP	2.62 *	1.46 ns	2.22 ns	1.53**
	72 DAP	3.82 *	2.63 ns	4.77 ns	1.82**
	86 DAP	1.06 ns	3.04 ns	3.36 ns	1.58**
	100 DAP	4.51 *	3.59 ns	5.44 ns	2.08**
	114 DAP	0.03 ns	4.52**	5.67**	0.87 ns
No. of inflorescences					
	79 DAP	3.23**	2.40**	3.21**	0.32 ns
	107 DAP	0.26 ns	2.46 *	0.61 ns	0.64 ns
	135 DAP	0.07 ns	20.06**	76.18**	2.82 ns
Total inflorescences		4.35 ns	16.11**	52.33**	2.14 ns
No. of marketable fruit					
	January	54.36**	55.22**	54.52**	4.10 ns
	February	120.67**	58.10**	163.99**	9.55 ns
	March	2.94 ns	492.60**	695.86**	41.87 ns
	Season	471.91**	944.18**	339.97 *	63.78 ns
Marketable fruit weight					
	January	47495.37**	35997.89**	39333.37**	3606.44 ns
	February	29082.19 *	33118.04**	29939.03**	4434.31 ns
	March	53.25 ns	152272.13**	281774.79**	14549.94 ns
	Season	185012.04**	421118.66**	174195.93**	24297.04 ns
Total fruit weight					
	January	51658.46**	40113.19**	47038.52**	3860.40 ns
	February	59912.86**	38671.36**	52123.75**	5088.12 ns
	March	15262.97 ns	232881.50**	260084.77**	21873.88 ns
	Season	390320.74**	571092.19**	136189.36 *	31924.27 ns
Average fruit weight					
	January	0.01 ns	160.61 *	112.00 ns	52.59 ns
	February	118.74 ns	568.42 *	474.20 *	130.96**
	March	0.05 ns	17.59 ns	101.76**	15.12 ns
	Season	2.75 ns	27.53 ns	81.71 *	17.49**
Fruit firmness	148 DAP	0.01 ns	37.86**	4.14 ns	2.71**
	153 DAP	0.31 ns	24.68**	2.82 ns	1.92**

*,** Significant at $P = 0.05$ and 0.01, respectively.

inflorescences 107 DAP and fruit firmness in the male. Conversely, female x male differences were significant only for vigor, number of runners 160 DAP, average fruit weight in February and March, and fruit firmness. All interactions with set (set x female, set x male, set x female x male) were not significant except for number of inflorescences 79 DAP (set x male), average fruit weight in February (set x male), and firmness 148 and 153 DAP (set x female x male). This indicates that the set to which a genotype belongs generally will not affect that genotype's performance in terms of the traits measured.

The comparison of selected and randomly picked sets is shown in Table 9-4. Plants in the selected set produced fewer runners and crowns than plants in the randomly picked set but the differences were not significant at $P=0.05$. Daughter plants from selected seedlings were generally more vigorous than daughter plants from randomly picked seedlings. Vigor was rated a month after planting and every two weeks thereafter. The randomly picked set had significantly lower vigor than the selected set up to 72 DAP and at 100 DAP. The most notable difference in vigor among sets was during the first month.

Branch crowns were obsereved to be bigger and the bases thicker in plants in the selected set. Hence, though a plant might have fewer crowns, these crowns tended to be bigger. Plants in the selected group therefore had higher vigor ratings than plants in the randomly picked group. While the selected and randomly picked sets did not vary significantly in number of crowns, the higher vigor in selected plants may have contributed to the production of more inflorescences 79 DAP by plants in this group.

Selection seemed to favor earlier bearing plants over later bearing plants. The selected set had higher January and February marketable yield than the randomly picked

Table 9-4. Vegetative and reproductive attributes[1] of plants in the fruiting field from selected and randomly picked seedlings at Dover, Florida (1995-1996).

Trait		Selected	Randomly picked
No. of runners	83 DAP	0.64	0.79
	160 DAP	0.03	0.04
Total no. of runners		0.66	0.82
No. of crowns	57 DAP	2.89	3.03
	85 DAP	4.79	4.91
	113 DAP	9.24	9.62
Vigor	30 DAP	3.57 a	3.30 b
	44 DAP	3.82 a	3.67 b
	58 DAP	3.99 a	3.88 b
	72 DAP	4.21 a	4.08 b
	86 DAP	4.27	4.20
	100 DAP	4.09 a	3.95 b
	114 DAP	4.13	4.10
No. of inflorescences	79 DAP	0.50 a	0.38 b
	107 DAP	0.70	0.66
	135 DAP	4.40	4.40
Total no. of inflorescences		5.61	5.45
No. of marketable fruit	January	1.62 a	1.08 b
	February	5.56 a	4.84 b
	March	14.66	14.40
	Season	22.00 a	20.37 b
Marketable fruit weight	January	46.65 a	30.72 b
	February	116.69	106.42
	March	258.66	255.66
	Season	425.57 a	393.85 b
Total fruit weight	January	49.86 a	33.10 b
	February	134.38 a	118.91 b
	March	340.45	328.75
	Season	528.16 a	481.96 b
Average fruit weight	January	29.81	29.74
	February	21.91	22.62
	March	17.73	17.70
	Season	19.39	19.28
Fruit firmness	148 DAP	3.36	3.39
	153 DAP	3.24	3.25

[1] Means in a row followed by different letters are significantly different at $P = 0.05$.

set. The higher early yield can be attributed to the higher number of inflorescences produced earlier in the season (79 DAP). Better vigor in the selected group up to 100 DAP (February 1) could also have contributed to the higher January and February yield. March yield did not differ between the selected and randomly picked sets. It is possible that the plants that bore little or no fruit at all early in the season started to catch up by the time March came. Total season yield was significantly higher in the selected than in the randomly picked set. It is reasonable to assume that the difference between the two sets is brought about by the difference in January and February yield.

Selection did not affect fruit size and firmness. Monthly and whole season average fruit weight was generally a little higher in the selected set than in the randomly picked set but the difference was not significant at *P*=0.05. Fruit firmness between the two sets was similar. Genotype may have some effect on firmness as shown by the significant female and female x male effects in Table 9-3. However, temperature and humidity during fruit development and ripening are two factors known to greatly affect fruit firmness (Scott et al., 1980 and Janick and Moore, 1996). Strawberry fruit harvested when temperatures are cool are firmer than those that ripen during warm humid weather (Scott et al. 1980).

Studies that have linked the size of a plant to its ability to flower include those by Eriksson (1988) and Slade and Hutchings (1989). In these studies, a positive relationship between ramet size and flowering in *Potentilla anserina* and *Glechoma hederacea* was observed. Both species have rosette growth habits and reproduce sexually and through the production of stolons. Eriksson (1988) suggests that stolon and probably flower initiation occur when a certain “resource level” within a ramet is reached.

In strawberries, Albregts and Howard (1985) found that the number of leaves of plants set out in the field affected plant size and eventually yield. Bigger (more vigorous) plants may have reached that "resource level" referred to by Eriksson (1988) at an earlier stage of growth so that yield was higher in these plants.

While it was difficult to obtain daughter plants of exactly the same size, care was taken so that the plants taken from selected and randomly picked seedlings did not differ dramatically in size. It is probable that physiological conditions in the more vigorous seedling plants in the nursery could have led to the production of daughter plants that grew faster in the fruiting field and, hence, tended to produce more inflorescences and fruit earlier.

Non-significant interaction effects with set suggest that genotypes will perform similarly relative to each other regardless of which set they belong to. Good genotypes will perform well, while inferior genotypes will be mediocre. Selection gives the better genotypes an edge by starting with plants that come from vigorous mother plants. A separate analysis of the selected and the randomly picked sets showed that some of the genotypes used as parents performed consistently better than other genotypes in both sets. In terms of January yield, FL90-10 and FL89-123 among the female parents, and 'Selva' and 'Oso Grande' among the male parents, consistently had the highest number and weight of marketable fruit and total fruit weight among the parent genotypes. FL90-10 and FL87-236 among the females, and 'Oso Grande' and 'Camarosa' among the males, had the highest total yield among the parent genotypes used.

The significant difference between sets indicates that the selected set performs better than the randomly picked set. Results show that early and total yield were higher in selected than in randomly picked sets. Selection in the nursery can therefore improve marketable yield in January, February, and the whole season during the first year of field evaluation.

Selection for high early yield in the nursery using visual inspection of seedlings may not always be effective. This study has shown that families have different responses. Some families have good performance in both nursery and fruiting field, some may only look good in the nursery, and some perform well only in the fruiting field. This last group is a cause for concern because plants not selected in the nursery are disposed of, leading to the loss of potentially good breeding lines.

The microenvironment around a plant will influence the growth of that plant. Seedlings from each of the 24 families were planted in single rows in the nursery. While the families were distributed randomly throughout the field, it is probable that some families, or even some seedlings from a family, grew in better spots than other families or seedlings. This could account for some of the difference in vigor in the nursery. Eliminating or reducing the differences in microenvironment will allow better assessment of the effectiveness of nursery selection.

CHAPTER 10
CONCLUSIONS

Yield component analysis performed on a sample of genotypes from the University of Florida strawberry breeding population showed that the number of marketable fruit and average fruit weight in January contributed significantly to season marketable fruit weight and season total weight. Regression coefficients were high and significant, indicating that the equations tested could be used to predict the dependent variables.

Correlation analysis showed significant correlation among and between vegetative and reproductive traits. There was high correlation among vigor rated at different periods during the season. Vigor was also correlated with number of crowns. Number of runners was positively correlated with early vigor, but negatively correlated with number of crowns. There may be some competition for assimilates between runners and crowns.

Most of the correlation coefficients between vegetative and reproductive traits are significant but low, indicating that other factors also play an important role in fruit production. Vigor 30 DAP and number of inflorescences were positively correlated. Number of inflorescences and number of crowns were generally positively correlated. Vigor 30 DAP was correlated with January yield. Vigor 58 to 114 DAP was correlated with March and season yield.

January yield was negatively correlated with March yield. Monthly measures of yield were all positively correlated with whole season yield. This is an indication that increases in monthly yield are associated with an increase in whole season yield. Correlation coefficients increased as the months progressed, becoming higher in March than in January and February. Thus, high early yield is associated with an increase in the total season yield, but the association is not as strong as that between March and total season yield. However, given the high price for strawberries in January, the grower can do well financially with a relatively low final yield, assuming that low production occurs late in the season.

Combining ability analysis showed more traits had significant GCA effects than SCA effects. The importance of GCA effects in this study suggests the predominance of additive genetic effects in the Florida strawberry breeding population.

Variance components and additive genetic variance of vegetative and production traits were generally higher among the female parents (i.e. University of Florida genotypes) than among the male parents (i.e. University of California genotypes). This indicates that there is more variability in the female population for the traits of interest, namely early yield and fruit size and firmness. Estimates of additive variance were usually higher than estimates of dominance variance. It is possible that these estimates of additive variance were biased upward due to possible inbreeding effects.

Family heritability and individual heritability were higher among female parents than among male parents. Since selection in strawberries is usually done on individual plants, heritabilities calculated based on individual plant observations are more meaningful. Estimates obtained for traits measured over time, such as vigor and monthly yield, showed variation as the season progressed. Heritability for vigor was higher during the first month and toward the last months than in the middle of the fruit production season. The heritability for number of inflorescences was highest 79 DAP. The number of inflorescences 79 DAP was found to be correlated with number and weight of marketable fruit and total fruit weight in January. The UF breeding program does not currently consider data on inflorescences, but it might be worthwhile to count inflorescences early in the season when selecting for high early yield.

Estimates of variance components, additive and dominance variances, and narrow sense heritability were generally smaller from part-records than from complete records. In spite of the lower estimates using part-records, the estimate of heritability for January shows the same relationship relative to heritability for March yield as in complete records. Thus, the use of part-records to estimate genetic parameters still provides useful information.

Genetic correlations among number of crowns, number of runners and vigor follow the phenotypic correlation trend. Number of runners is generally negatively correlated with number of crowns and vigor. Number of crowns and vigor generally have high positive genetic correlation.

Vigor and number of inflorescences were generally positively correlated. Number of runners was positively correlated with number of inflorescences 79 and 107 DAP, but negatively correlated with number of inflorescences 135 DAP and total number of inflorescences. Number of runners was also negatively correlated with January yield. Vigor was generally positively correlated with monthly number and weight of marketable fruit. Vigor 30 and 44 DAP showed very high correlation with the number and weight of marketable fruit in January in the female. High correlation coefficients were also obtained between vigor 44, 72 and 86 DAP and marketable fruit weight in February. Similarly, there was high correlation between the vigor ratings later in the season and March yield. These results suggest that plant vigor in the period before fruit production can be an important indication of the amount of fruit that will be produced for that period.

Number of inflorescences 79 DAP and weight of marketable fruit in January and February showed high positive correlation. The high correlation is significant, because the number of inflorescences in January can be an indication of January yield and can be used to predict it. Furthermore, the moderately high narrow sense heritability of 0.45 for number of inflorescences 79 DAP indicates that offspring selected on the basis of high early inflorescence number are likely to possess genes for this trait.

Number of fruit in each month had high correlation with marketable fruit weight for that month. This indicates that marketable fruit weight may be improved by selecting for more fruit. Number of fruit in each month also showed high positive correlation with season marketable fruit weight, indicating that selection for high monthly fruit number would indirectly select for high total marketable fruit weight. The correlation coefficient was lowest for January and increased for February and March.

Genotypes selected in the nursery, based on crown size and plant vigor, were more vigorous, produced more inflorescences 79 DAP, and generally had higher number and weight of marketable fruit, and total fruit weight, in January, February, and for the season than genotypes picked at random from the nursery.

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APPENDIX

Table 1. Estimates of general combining ability in runner production of strawberry genotypes used as parents at Dover, Florida (1994-1995).

Genotype	46 DAP	91 DAP	Total
FL87-236	0.27	0.05	0.34
FL90-51	-0.06	0.10	0.04
FL91-37	-0.11	-0.08	-0.20
FL91-48	0.14	0.11	0.03
Sweet Charlie	-0.25	-0.18	-0.45
Anaheim	0.03	0.07	0.15
Camarosa	-0.03	-0.05	-0.13
Carlsbad	0.02	0.14	0.14
Cuesta	0.00	0.08	0.06
Laguna	-0.04	-0.18*	-0.23
Sunset	0.01	-0.05	0.00

* Significantly different from zero at p=0.05.

Table 2. Estimates of general combining ability in crown production of strawberry genotypes used as parents at Dover, Florida (1994-1995).

Genotype	92 DAP
FL87-236	-0.02
FL90-51	-0.06
FL91-37	0.74**
FL91-48	-0.30
Sweet Charlie	-0.36
Anaheim	0.22
Camarosa	0.14
Carlsbad	-0.29
Cuesta	0.14
Laguna	-0.22
Sunset	0.00

** Significantly different from zero at p=0.01.

Table 3. Estimates of general combining ability in vigor of strawberry genotypes used as parents at Dover, Florida (1994-1995).

Genotype	27 DAP	42 DAP	57 DAP	69 DAP
FL87-236	0.07	0.09	0.11	0.06
FL90-51	-0.11	-0.07	-0.12	-0.08
FL91-37	0.08	0.13	0.29	0.20
FL91-48	-0.07	-0.17	-0.33	-0.28
Sweet Charlie	0.03	0.02	0.05	0.10
Anaheim	0.04	0.07	0.04	-
Camarosa	-0.01	0.01	-0.00	-
Carlsbad	0.08	0.05	0.02	-
Cuesta	0.11	0.02	0.03	-
Laguna	-0.15	-0.09	-0.05	-
Sunset	-0.07	-0.05	-0.04	-

Table 4. Estimates of general combining ability in number of marketable fruit of strawberry genotypes used as parents at Dover, Florida (1994-1995).

Genotype	January	February	March	Season
FL87-236	0.41	0.24	0.85	1.88
FL90-51	-0.38	-0.48	-0.73	-1.94
FL91-37	-0.07	0.24	0.00	0.20
FL91-48	-0.36	-0.66	-0.63	-1.96
Sweet Charlie	0.39	0.65	0.50	1.82
Anaheim	-0.13	-	0.46	0.11
Camarosa	0.28	-	-0.17	0.28
Carlsbad	0.20	-	0.60	0.76
Cuesta	-0.08	-	-0.37	-0.28
Laguna	0.04	-	0.44	0.35
Sunset	-0.30	-	-0.95	-1.22

Table 5. Estimates of general combining ability in weight (g) of marketable fruit of strawberry genotypes used as parents at Dover, Florida (1994-1995).

Genotype	January	February	March	Season
FL87-236	16.00*	7.61	22.01	55.31
FL90-51	-12.96	-7.77	-20.99	-51.42
FL91-37	0.65	3.96	3.85	11.67
FL91-48	-12.62	-9.49	-16.65	-47.94
Sweet Charlie	8.93	5.68	11.79	32.38
Anaheim	-3.35	-6.46	11.22	-0.92
Camarosa	9.40	5.31	-4.67	10.47
Carlsbad	6.79	3.28	19.84	31.45
Cuesta	-3.33	2.88	-13.02	-11.64
Laguna	-0.31	-1.82	7.81	5.07
Sunset	-9.20	-3.19	-21.18	-34.43

* Significantly different from zero at p=0.05.

Table 6. Estimates of general combining ability in total weight (g) of fruit of strawberry genotypes used as parents at Dover, Florida (1994-1995).

Genotype	January	February	March	Season
FL87-236	16.73*	8.35	24.23	56.92
FL90-51	-13.38	-9.15	-24.76	-56.36
FL91-37	0.59	4.28	6.64	15.68
FL91-48	-13.60	-10.42	-19.01	-51.87
Sweet Charlie	9.66	6.93	12.89	35.62
Anaheim	-4.02	-9.03	11.11	-4.16
Camarosa	9.95	7.04	-4.83	12.16
Carlsbad	8.45	5.23	26.93	41.38
Cuesta	-3.70	2.55	-17.76	-17.10
Laguna	-0.58	-1.56	9.53	7.70
Sunset	-10.11*	-4.23	-24.97	-39.98

* Significantly different from zero at p=0.05.

Table 7. Estimates of general combining ability in average fruit weight (g) of strawberry genotypes used as parents at Dover, Florida (1994-1995).

Genotype	January	February	March	Season
FL87-236	1.93	0.55	-	0.54
FL90-51	-1.82	0.12	-	-0.27
FL91-37	1.64	-0.01	-	0.38
FL91-48	-1.57	0.16	-	-0.20
Sweet Charlie	-0.17	-082	-	-0.46
Anaheim	-0.20	-	-0.12	-0.26
Camarosa	0.42	-	-0.27	0.01
Carlsbad	0.90	-	1.05*	0.83*
Cuesta	-1.04	-	-0.60	-0.43
Laguna	-0.99	-	-0.51	-0.30
Sunset	0.90	-	0.44	0.16

* Significantly different from zero at p=0.05.

Table 8. Estimates of general combining ability in fruit firmness of strawberry genotypes used as parents at Dover, Florida (1994-1995).

Genotype	91 DAP	99 DAP	106 DAP
FL87-236	0.10	-0.02	-0.09
FL90-51	0.07	0.11	0.06
FL91-37	0.05	0.16	0.27*
FL91-48	-0.09	-0.04	0.01
Sweet Charlie	-0.13	-0.21	-0.26*
Anaheim	-	-0.24	-0.29**
Camarosa	-	0.02	0.01
Carlsbad	-	0.23	0.26*
Cuesta	-	-0.01	-0.13
Laguna	-	0.02	0.08
Sunset	-	-0.03	0.07

* Significantly different from zero at p=0.05.

** Significantly different from zero at p=0.01.

Table 8. Continued.

Genotype	112 DAP	119 DAP	133 DAP
FL87-236	-0.07	-0.26	-0.03
FL90-51	0.30	0.26	0.21
FL91-37	0.19	0.39*	0.15
FL91-48	-0.01	-0.19	-0.13
Sweet Charlie	-0.41**	-0.21	-0.20
Anaheim	-0.02	-0.25	-0.15
Camarosa	-0.05	-0.05	-0.02
Carlsbad	0.08	0.15	0.30*
Cuesta	-0.03	-0.15	-0.25
Laguna	-0.01	0.03	0.03
Sunset	0.03	0.27*	0.09

Table 9. Estimates of general combining ability in runner production of strawberry genotypes used as parents at Dover, Florida (1995-1996).

Genotype	83 DAP	160 DAP	Total
FL87-236	0.45*	-0.00	0.44*
FL89-123	-0.18	-0.00	-0.19
FL90-10	0.23	-0.00	0.22
FL92-28	0.20	0.00	0.23
Rosa Linda	-0.36	-0.00	-0.38
Sweet Charlie	-0.34	-0.00	-0.31
Camarosa	-0.06	-0.02	-0.10
Cuesta	-0.01	-0.00	-0.01
Oso Grande	0.22	0.03	0.30
Selva	-0.15	-0.01	-0.18

* Significantly different from zero at p=0.05.

Table 10. Estimates of general combining ability in crown production of strawberry genotypes used as parents at Dover, Florida (1995-1996).

Genotype	57 DAP	85 DAP	113 DAP
FL87-236	0.28	0.37	0.14
FL89-123	0.04	-0.31	0.00
FL90-10	-0.03	-0.16	-0.62
FL92-28	-0.34*	-0.32	-0.23
Rosa Linda	0.18	0.37	0.77
Sweet Charlie	-0.12	0.04	-0.05
Camarosa	0.17	0.20	1.41
Cuesta	0.08	0.65*	1.08
Oso Grande	-0.18	-0.62	-1.06
Selva	-0.08	-0.23	-1.43

* Significantly different from zero at p=0.05.

Table 11. Estimates of general combining ability in vigor of strawberry genotypes used as parents at Dover, Florida (1995-1996).

Genotype	30 DAP	44 DAP	58 DAP	72 DAP
FL87-236	-0.06	0.04	0.03	0.14
FL89-123	0.05	0.01	-0.01	-0.14
FL90-10	0.19*	0.06	0.04	0.03
FL92-28	-0.14	-0.13	-0.09	-0.18
Rosa Linda	0.13	0.09	0.06	0.18
Sweet Charlie	-0.15	-0.07	-0.02	-0.04
Camarosa	-0.04	-	0.02	0.06
Cuesta	0.04	-	0.01	0.15
Oso Grande	-0.08	-	-0.01	-0.12
Selva	0.08	-	-0.01	-0.09

* Significantly different from zero at p=0.05.

Table 11. Continued.

Genotype	86 DAP	100 DAP	114 DAP
FL87-236	0.14	0.05	0.08
FL89-123	-0.13	-0.21	-0.20
FL90-10	0.01	0.03	-0.10
FL92-28	-0.17	-0.14	-0.03
Rosa Linda	0.17	0.31*	0.30*
Sweet Charlie	-0.01	-0.04	-0.05
Camarosa	0.02	0.02	0.13
Cuesta	0.14	0.20	0.26
Oso Grande	-0.10	-0.12	-0.15
Selva	-0.07	-0.09	-0.24

Table 12. Estimates of general combining ability in inflorescence production of strawberry genotypes used as parents at Dover, Florida (1995-1996).

Genotype	79 DAP	107 DAP	135 DAP	Total
FL87-236	-0.10	0.10	0.39	0.41
FL89-123	0.16	-0.13	-0.31	-0.34
FL90-10	0.22**	0.05	-0.41	-0.16
FL92-28	-0.16	-0.00	-0.25	-0.37
Rosa Linda	-0.01	-0.01	0.16	0.14
Sweet Charlie	-0.10	-0.00	0.41	0.32
Camarosa	-0.04	-0.09	0.67	0.46
Cuesta	-0.18*	0.06	0.63	0.52
Oso Grande	0.10	-0.00	-0.48	-0.36
Selva	0.11	0.04	-0.82	-0.62

* Significantly different from zero at p=0.05.

** Significantly different from zero at p=0.01.

Table 13. Estimates of general combining ability in number of marketable fruit of strawberry genotypes used as parents at Dover, Florida (1995-1996).

Genotype	January	February	March	Season
FL87-236	-0.37	-0.08	2.70*	2.40
FL89-123	0.16	-0.51	-2.01	-2.55
FL90-10	0.90**	1.36**	0.76	3.17*
FL92-28	-0.70*	-0.63	-1.34	-2.80
Rosa Linda	-0.09	0.22	0.92	1.14
Sweet Charlie	0.09	-0.36	-1.03	-1.36
Camarosa	-0.19	-1.12	1.00	-0.17
Cuesta	-0.56	-0.59	1.28	0.07
Oso Grande	0.22	0.34	0.86	0.89
Selva	0.54	1.38	-3.14*	-0.79

* Significantly different from zero at p=0.05.

** Significantly different from zero at p=0.01.

Table 14. Estimates of general combining ability in weight (g) of marketable fruit of strawberry genotypes used as parents at Dover, Florida (1995-1996).

Genotype	January	February	March	Season
FL87-236	-9.16	12.79	51.02*	60.82*
FL89-123	4.49	-21.59	-32.08	-54.13
FL90-10	24.81**	27.45*	10.92	67.19*
FL92-28	-19.62*	-13.64	-26.93	-65.24*
Rosa Linda	1.13	3.96	16.00	23.47
Sweet Charlie	-1.65	-8.97	-18.93	-32.11
Camarosa	-4.95	-11.85	35.74	11.60
Cuesta	-15.24	-8.07	17.51	-5.80
Oso Grande	4.76	5.20	13.61	18.30
Selva	15.43*	14.72	-66.86*	-24.10

* Significantly different from zero at p=0.05.

** Significantly different from zero at p=0.01.

Table 15. Estimates of general combining ability in total fruit weight (g) of strawberry genotypes used as parents at Dover, Florida (1995-1996).

Genotype	January	February	March	Season
FL87-236	-9.33	10.32	57.19*	63.69
FL89-123	7.04	-20.90	-44.84	-63.84
FL90-10	24.76**	33.92**	20.38	84.62*
FL92-28	-21.46*	-18.49	-38.04	-84.87*
Rosa Linda	-0.17	5.18	18.78	26.37
Sweet Charlie	-0.84	-10.02	-13.47	-25.96
Camarosa	-3.45	-14.50	33.00	7.32
Cuesta	-16.92*	-11.44	20.05	-4.98
Oso Grande	4.06	4.86	14.02	12.97
Selva	16.30	21.08	-67.07*	-15.31

* Significantly different from zero at p=0.05.

** Significantly different from zero at p=0.01.

Table 16. Estimates of general combining ability in average fruit weight (g) of strawberry genotypes used as parents at Dover, Florida (1995-1996).

Genotype	January	February	March	Season
FL87-236	1.39	3.33*	0.10	0.23
FL89-123	-1.03	-2.25	0.30	0.06
FL90-10	-0.26	-0.36	-0.14	0.07
FL92-28	1.02	-0.53	-0.15	-0.19
Rosa Linda	2.09	-0.39	-0.03	-0.04
Sweet Charlie	-3.21*	0.21	-0.08	-0.13
Camarosa	-	1.99	0.89	0.73
Cuesta	-	0.38	-0.29	-0.42
Oso Grande	-	-0.28	0.11	0.05
Selva	-	-2.09	-0.71	-0.36

* Significantly different from zero at p=0.05.

Table 17. Estimates of general combining ability in fruit firmness of strawberry genotypes used as parents at Dover, Florida (1995-1996).

Genotype	148 DAP	153 DAP
FL87-236	-0.11	-0.16
FL89-123	0.40**	0.35
FL90-10	-0.39**	-0.60**
FL92-28	0.27	0.49*
Rosa Linda	-0.06	0.02
Sweet Charlie	-0.10	-0.10
Camarosa	-	-
Cuesta	-	-
Oso Grande	-	-
Selva	-	-

* Significantly different from zero at p=0.05.

** Significantly different from zero at p=0.01.

Table 18. Estimates of specific combining ability in runner and crown production of strawberry crosses at Dover, Florida (1994-1995).

Cross	Number of runners		Number of crowns
	46 DAP	Total	
FL87-236 x Anaheim	-0.32	-0.37	-0.10
FL87-236 x Camarosa	0.17	0.22	0.06
FL87-236 x Carlsbad	0.22	0.39	0.03
FL87-236 x Cuesta	0.17	0.24	-0.00
FL87-236 x Laguna	-0.14	-0.27	0.01
FL87-236 x Sunset	0.41	0.24	-0.00
FL90-51 x Anaheim	0.39	0.50	0.16
FL90-51 x Camarosa	-0.12	-0.05	-0.03
FL90-51 x Carlsbad	-0.10	0.06	-0.14
FL90-51 x Cuesta	0.17	0.17	0.19
FL90-51 x Laguna	-0.41	-0.52	-0.12
FL90-51 x Sunset	-0.04	-0.12	-0.08
FL91-37 x Anaheim	-0.10	-0.23	0.00
FL91-37 x Camarosa	-0.13	-0.12	0.27
FL91-37 x Carlsbad	0.15	0.11	-0.10
FL91-37 x Cuesta	-0.10	-0.05	-0.08
FL91-37 x Laguna	-0.10	-0.05	0.03
FL91-37 x Sunset	0.06	0.08	0.09
FL91-48 x Anaheim	0.82**	0.86**	0.04
FL91-48 x Camarosa	-0.48	-0.57	-0.16
FL91-48 x Carlsbad	0.12	0.10	0.02
FL91-48 x Cuesta	-0.01	0.04	-0.06
FL91-48 x Laguna	0.09	0.17	-0.03
FL91-48 x Sunset	-0.38	-0.48	0.21
Sweet Charlie x Anaheim	-0.11	-0.22	0.10
Sweet Charlie x Camarosa	-0.17	-0.16	0.08
Sweet Charlie x Carlsbad	-0.02	-0.15	-0.06
Sweet Charlie x Cuesta	-0.17	-0.17	0.08
Sweet Charlie x Laguna	-0.22	-0.16	-0.09
Sweet Charlie x Sunset	0.21	0.30	-0.22

** Significantly different from zero at p=0.01.

Table 19. Estimates of specific combining ability in vigor of strawberry crosses at Dover, Florida (1994-1995).

Cross	27 DAP	42 DAP	57 DAP	69 DAP
FL87-236 x Anaheim	0.17	0.23	0.31	0.48*
FL87-236 x Camarosa	0.10	0.28	0.23	0.16
FL87-236 x Carlsbad	0.43*	0.46	0.21	0.05
FL87-236 x Cuesta	0.22	0.16	0.32	0.16
FL87-236 x Laguna	-0.39*	-0.52*	-0.52*	-0.17
FL87-236 x Sunset	-0.15	-0.11	-0.31	-0.49*
FL90-51 x Anaheim	0.09	0.13	0.15	0.04
FL90-51 x Camarosa	0.02	0.29	0.07	0.26
FL90-51 x Carlsbad	-0.13	0.15	0.06	0.04
FL90-51 x Cuesta	0.04	-0.04	0.16	0.04
FL90-51 x Laguna	-0.47*	-0.83**	-0.56*	-0.23
FL90-51 x Sunset	-0.13	-0.10	-0.12	-0.39
FL91-37 x Anaheim	-0.24	-0.13	-0.18	-0.06
FL91-37 x Camarosa	0.39*	0.35	0.42	0.37
FL91-37 x Carlsbad	-0.06	0.32	0.18	0.16
FL91-37 x Cuesta	0.02	-0.20	-0.16	-0.06
FL91-37 x Laguna	0.39*	0.53*	0.46	0.59*
FL91-37 x Sunset	-0.06	-0.14	0.11	-0.38
FL91-48 x Anaheim	0.07	0.32	0.21	-0.03
FL91-48 x Camarosa	-0.49	-0.65	-0.42	-0.70*
FL91-48 x Carlsbad	0.14	0.01	0.11	0.19
FL91-48 x Cuesta	-0.08	-0.18	-0.35	-0.03
FL91-48 x Laguna	0.00	-0.11	-0.28	-0.57*
FL91-48 x Sunset	0.05	-0.02	0.38	0.51*
Sweet Charlie x Anaheim	0.10	0.29	0.36	0.23
Sweet Charlie x Camarosa	0.03	0.11	0.05	0.02
Sweet Charlie x Carlsbad	-0.03	-0.35	-0.19	-0.31
Sweet Charlie x Cuesta	0.25	0.44	0.60*	0.56*
Sweet Charlie x Laguna	-0.17	-0.14	-0.13	0.02
Sweet Charlie x Sunset	-0.02	-0.27	-0.59*	-0.20

* Significantly different from zero at p=0.05.

** Significantly different from zero at p=0.01.

Table 20. Estimates of specific combining ability in number of marketable fruit of strawberry crosses at Dover, Florida (1994-1995).

Cross	February	March	Season
FL87-236 x Anaheim	0.17	-0.28	-0.06
FL87-236 x Camarosa	0.10	0.99	1.02
FL87-236 x Carlsbad	0.02	0.34	0.40
FL87-236 x Cuesta	0.34	-0.07	0.02
FL87-236 x Laguna	-0.01	1.62	1.28
FL87-236 x Sunset	-0.41	-0.95	-1.71
FL90-51 x Anaheim	-0.74	0.47	-0.17
FL90-51 x Camarosa	0.33	-0.41	-0.02
FL90-51 x Carlsbad	-0.26	-0.37	-0.44
FL90-51 x Cuesta	-0.07	-1.48	-1.46
FL90-51 x Laguna	-0.02	0.92	0.98
FL90-51 x Sunset	0.37	-0.53	0.14
FL91-37 x Anaheim	0.05	1.39	1.56
FL91-37 x Camarosa	0.46	-0.34	0.11
FL91-37 x Carlsbad	0.22	-0.37	-0.11
FL91-37 x Cuesta	-0.07	-0.32	-0.50
FL91-37 x Laguna	0.15	-0.10	0.11
FL91-37 x Sunset	-0.61	-0.26	-1.06
FL91-48 x Anaheim	-0.56	-0.09	-0.52
FL91-48 x Camarosa	0.11	-1.47	-1.50
FL91-48 x Carlsbad	0.60	0.46	1.10
FL91-48 x Cuesta	0.23	0.96	1.20
FL91-48 x Laguna	-0.54	-1.16	-1.33
FL91-48 x Sunset	-0.34	-0.41	-0.50
Sweet Charlie x Anaheim	0.02	-0.48	-0.56
Sweet Charlie x Camarosa	0.21	0.36	0.45
Sweet Charlie x Carlsbad	-0.34	1.25	0.74
Sweet Charlie x Cuesta	0.11	0.11	0.12
Sweet Charlie x Laguna	0.02	-0.33	-0.29
Sweet Charlie x Sunset	0.52	0.07	0.44

Table 21. Estimates of specific combining ability in marketable fruit weight (g) of strawberry crosses at Dover, Florida (1994-1995).

Cross	January	February	March	Season
FL87-236 x Anaheim	0.27	4.63	-1.14	4.66
FL87-236 x Camarosa	0.35	2.06	21.74	26.36
FL87-236 x Carlsbad	0.40	-1.32	6.38	7.56
FL87-236 x Cuesta	-0.11	8.08	-8.46	-7.61
FL87-236 x Laguna	-0.24	6.47	28.56	28.30
FL87-236 x Sunset	-0.46	-5.23	-17.51	-34.15
FL90-51 x Anaheim	-0.20	-17.06	8.83	-5.21
FL90-51 x Camarosa	0.07	8.45	-6.79	5.64
FL90-51 x Carlsbad	-0.03	-9.10	-3.51	-9.42
FL90-51 x Cuesta	-0.13	-0.49	-27.66	-28.28
FL90-51 x Laguna	-0.05	-0.86	15.72	18.38
FL90-51 x Sunset	0.18	4.07	-14.81	-4.49
FL91-37 x Anaheim	0.10	0.26	27.44	30.17
FL91-37 x Camarosa	0.12	11.51	-9.60	1.35
FL91-37 x Carlsbad	0.05	3.51	-5.30	-3.19
FL91-37 x Cuesta	-0.05	-6.56	-5.33	-14.34
FL91-37 x Laguna	0.14	7.63	1.41	9.95
FL91-37 x Sunset	-0.37	-8.71	-3.44	-18.64
FL91-48 x Anaheim	-0.14	-15.11	-3.76	-15.73
FL91-48 x Camarosa	-0.44	-1.62	-32.89	-41.48
FL91-48 x Carlsbad	-0.04	20.85	-7.88	29.98
FL91-48 x Cuesta	0.04	9.45	19.92	32.99
FL91-48 x Laguna	0.06	-16.71	-25.53	-37.29
FL91-48 x Sunset	0.21	-12.42	-1.35	-5.50
Sweet Charlie x Anaheim	-0.15	2.75	-13.36	-15.24
Sweet Charlie x Camarosa	0.08	2.50	6.67	8.15
Sweet Charlie x Carlsbad	-0.13	-1.52	26.43	20.95
Sweet Charlie x Cuesta	0.13	0.44	0.63	0.25
Sweet Charlie x Laguna	0.07	-3.41	-7.62	-11.95
Sweet Charlie x Sunset	0.11	10.20	3.10	12.56

Table 22. Estimates of specific combining ability in total fruit weight (g) of strawberry crosses at Dover, Florida (1994-1995).

Cross	January	February	March	Season
FL87-236 x Anaheim	0.42	5.22	-2.97	3.16
FL87-236 x Camarosa	0.58	1.20	18.66	23.94
FL87-236 x Carlsbad	0.67	-0.53	10.14	10.21
FL87-236 x Cuesta	-0.24	7.11	-6.48	-6.93
FL87-236 x Laguna	-0.42	7.70	18.54	21.52
FL87-236 x Sunset	-0.69	-5.76	-15.84	-31.06
FL90-51 x Anaheim	-0.32	-18.31	8.53	-3.21
FL90-51 x Camarosa	0.05	8.56	-3.34	6.89
FL90-51 x Carlsbad	-0.07	-11.05	-4.82	-11.53
FL90-51 x Cuesta	-0.10	-1.48	-23.67	-26.57
FL90-51 x Laguna	-0.11	0.21	10.11	13.52
FL90-51 x Sunset	0.30	5.70	-9.34	0.26
FL91-37 x Anaheim	0.15	0.15	21.90	26.26
FL91-37 x Camarosa	0.23	12.28	-7.55	1.39
FL91-37 x Carlsbad	0.04	3.25	-7.07	-6.46
FL91-37 x Cuesta	-0.11	-7.69	-4.09	-13.28
FL91-37 x Laguna	0.29	8.29	5.92	14.28
FL91-37 x Sunset	-0.60	-8.62	-3.07	-16.44
FL91-48 x Anaheim	-0.21	-16.58	-4.26	-15.52
FL91-48 x Camarosa	-0.67	1.38	-27.84	-36.24
FL91-48 x Carlsbad	-0.09	23.56	6.32	26.34
FL91-48 x Cuesta	0.05	7.91	15.40	27.43
FL91-48 x Laguna	0.08	-17.00	-18.88	-31.00
FL91-48 x Sunset	0.36	-14.42	-0.50	-4.71
Sweet Charlie x Anaheim	-0.23	3.50	-12.45	-14.69
Sweet Charlie x Camarosa	0.07	0.36	2.94	0.99
Sweet Charlie x Carlsbad	-0.13	-0.17	21.52	21.12
Sweet Charlie x Cuesta	0.23	1.49	1.64	2.96
Sweet Charlie x Laguna	0.12	-3.71	-6.47	-10.93
Sweet Charlie x Sunset	0.12	10.93	4.56	13.59

Table 23. Estimates of specific combining ability in average weight (g) of marketable fruit of strawberry crosses at Dover, Florida (1994-1995).

Cross	January	February	March
FL87-236 x Anaheim	0.06	-0.41	0.12
FL87-236 x Camarosa	-0.05	0.16	0.17
FL87-236 x Carlsbad	0.01	0.02	-0.02
FL87-236 x Cuesta	-0.06	0.12	-0.32
FL87-236 x Laguna	0.03	0.72	-0.02
FL87-236 x Sunset	0.08	0.90	0.08
FL90-51 x Anaheim	0.01	0.53	-0.04
FL90-51 x Camarosa	0.12	0.64	-0.05
FL90-51 x Carlsbad	-0.02	-0.09	0.24
FL90-51 x Cuesta	-0.08	0.68	-0.09
FL90-51 x Laguna	-0.05	-0.14	-0.07
FL90-51 x Sunset	-0.05	-1.28	-0.54
FL91-37 x Anaheim	-0.11	-1.00	0.11
FL91-37 x Camarosa	0.03	0.26	-0.08
FL91-37 x Carlsbad	0.02	-0.26	0.19
FL91-37 x Cuesta	0.04	-0.52	0.14
FL91-37 x Laguna	0.06	0.53	0.41
FL91-37 x Sunset	0.02	0.95	0.08
FL91-48 x Anaheim	0.01	-0.59	-0.12
FL91-48 x Camarosa	-0.02	-0.97	-0.34
FL91-48 x Carlsbad	0.09	1.72	0.06
FL91-48 x Cuesta	-0.02	1.22	0.02
FL91-48 x Laguna	-0.10	-0.97	-0.36
FL91-48 x Sunset	-0.02	-0.45	0.42
Sweet Charlie x Anaheim	0.00	-0.47	-0.12
Sweet Charlie x Camarosa	-0.04	-0.13	0.06
Sweet Charlie x Carlsbad	-0.00	0.71	-0.01
Sweet Charlie x Cuesta	0.01	-0.73	-0.01
Sweet Charlie x Laguna	-0.05	-0.82	-0.17
Sweet Charlie x Sunset	0.07	-0.82	0.15

Table 24. Estimates of specific combining ability in fruit firmness of strawberry crosses at Dover, Florida (1994-1995).

Cross	91 DAP	99 DAP	106 DAP
FL87-236 x Anaheim	-0.02	0.25	0.01
FL87-236 x Camarosa	-0.06	-0.07	0.01
FL87-236 x Carlsbad	0.24	0.24	0.04
FL87-236 x Cuesta	0.31	-0.11	-0.01
FL87-236 x Laguna	-0.04	-0.22	-0.04
FL87-236 x Sunset	-0.07	-0.13	-0.02
FL90-51 x Anaheim	-0.31	-0.09	-0.02
FL90-51 x Camarosa	0.25	0.04	0.01
FL90-51 x Carlsbad	0.15	0.09	-0.02
FL90-51 x Cuesta	0.17	0.03	0.06
FL90-51 x Laguna	0.00	0.07	-0.00
FL90-51 x Sunset	0.01	0.10	-0.02
FL91-37 x Anaheim	0.25	0.02	-0.01
FL91-37 x Camarosa	-0.28	0.08	-0.02
FL91-37 x Carlsbad	0.15	0.32	0.02
FL91-37 x Cuesta	-0.01	0.05	0.02
FL91-37 x Laguna	0.22	0.16	0.04
FL91-37 x Sunset	-0.13	-0.29	0.01
FL91-48 x Anaheim	-0.24	-0.37	0.06
FL91-48 x Camarosa	-0.12	-0.06	-0.10
FL91-48 x Carlsbad	0.00	0.02	0.03
FL91-48 x Cuesta	-0.33	-0.17	-0.11
FL91-48 x Laguna	-0.07	-0.13	0.01
FL91-48 x Sunset	0.05	0.35	0.02
Sweet Charlie x Anaheim	-0.37	-0.27	-0.10
Sweet Charlie x Camarosa	0.06	-0.21	0.01
Sweet Charlie x Carlsbad	-0.08	-0.22	-0.02
Sweet Charlie x Cuesta	-0.40	0.17	0.02
Sweet Charlie x Laguna	0.19	0.16	-0.00
Sweet Charlie x Sunset	0.11	-0.08	0.04

Table 24. Continued.

Cross	112 DAP	119 DAP	133 DAP
FL87-236 x Anaheim	0.05	0.00	-0.02
FL87-236 x Camarosa	-0.10	-0.04	-0.04
FL87-236 x Carlsbad	0.05	-0.03	0.14
FL87-236 x Cuesta	-0.11	-0.08	-0.07
FL87-236 x Laguna	-0.03	0.10	-0.06
FL87-236 x Sunset	0.12	0.02	0.04
FL90-51 x Anaheim	-0.01	-0.01	-0.04
FL90-51 x Camarosa	-0.01	-0.01	0.09
FL90-51 x Carlsbad	0.05	-0.02	-0.03
FL90-51 x Cuesta	0.09	0.00	0.00
FL90-51 x Laguna	-0.06	0.02	0.06
FL90-51 x Sunset	0.02	0.05	0.02
FL91-37 x Anaheim	-0.04	0.01	-0.04
FL91-37 x Camarosa	-0.05	0.02	0.04
FL91-37 x Carlsbad	0.09	0.01	0.07
FL91-37 x Cuesta	-0.04	0.07	-0.02
FL91-37 x Laguna	0.05	-0.03	0.04
FL91-37 x Sunset	0.03	-0.03	-0.01
FL91-48 x Anaheim	0.10	-0.02	0.06
FL91-48 x Camarosa	-0.13	-0.10	-0.03
FL91-48 x Carlsbad	-0.06	-0.04	-0.08
FL91-48 x Cuesta	-0.05	0.01	0.11
FL91-48 x Laguna	-0.02	0.01	-0.09
FL91-48 x Sunset	-0.02	0.06	-0.05
Sweet Charlie x Anaheim	-0.17	-0.05	-0.03
Sweet Charlie x Camarosa	-0.04	0.07	-0.10
Sweet Charlie x Carlsbad	0.11	0.12	0.03
Sweet Charlie x Cuesta	0.03	-0.05	-0.12
Sweet Charlie x Laguna	0.04	-0.09	0.08
Sweet Charlie x Sunset	-0.06	-0.03	0.04

Table 25. Estimates of specific combining ability in runner and crown production of strawberry crosses at Dover, Florida (1995-1996).

Cross	Number of runners	Number of crowns
	83 DAP	57 DAP
FL87-236 x Camarosa	-0.01	0.02
FL87-236 x Cuesta	-0.02	0.03
FL87-236 x Oso Grande	0.03	-0.02
FL87-236 x Selva	-0.02	0.01
FL89-123 x Camarosa	-0.01	0.03
FL89-123 x Cuesta	-0.02	0.03
FL89-123 x Oso Grande	0.02	-0.03
FL89-123 x Selva	-0.02	-0.02
FL90-10 x Camarosa	-0.01	0.04
FL90-10 x Cuesta	-0.02	-0.06
FL90-10 x Oso Grande	-0.04	-0.01
FL90-10 x Selva	0.02	0.01
FL92-28 x Camarosa	-0.01	-0.03
FL92-28 x Cuesta	0.02	0.02
FL92-28 x Oso Grande	0.19**	0.01
FL92-28 x Selva	-0.02	-0.05
Rosa Linda x Camarosa	-0.01	0.03
Rosa Linda x Cuesta	-0.02	0.02
Rosa Linda x Oso Grande	-0.04	-0.01
Rosa Linda x Selva	-0.01	-0.00
Sweet Charlie x Camarosa	-0.01	-0.04
Sweet Charlie x Cuesta	0.06	-0.01
Sweet Charlie x Oso Grande	-0.04	0.02
Sweet Charlie x Selva	-0.01	0.02

** Significantly different from zero at p=0.01.

Table 26. Estimates of specific combining ability in vigor of strawberry crosses at Dover, Florida (1995-1996).

Cross	44 DAP	58 DAP	72 DAP
FL87-236 x Camarosa	0.08	0.16	0.09
FL87-236 x Cuesta	0.01	-0.03	0.01
FL87-236 x Oso Grande	-0.04	-0.08	-0.06
FL87-236 x Selva	0.00	0.03	0.05
FL89-123 x Camarosa	-0.03	0.01	0.03
FL89-123 x Cuesta	0.08	0.13	0.10
FL89-123 x Oso Grande	0.04	0.04	-0.02
FL89-123 x Selva	-0.08	-0.21	-0.19
FL90-10 x Camarosa	0.10	0.05	0.02
FL90-10 x Cuesta	-0.02	0.01	-0.03
FL90-10 x Oso Grande	0.00	0.04	0.01
FL90-10 x Selva	-0.01	-0.00	0.03
FL92-28 x Camarosa	0.04	0.02	-0.03
FL92-28 x Cuesta	-0.03	-0.11	-0.06
FL92-28 x Oso Grande	-0.21	-0.13	-0.04
FL92-28 x Selva	0.05	-0.02	0.03
Rosa Linda x Camarosa	-0.00	0.10	0.02
Rosa Linda x Cuesta	0.11	0.11	0.10
Rosa Linda x Oso Grande	-0.01	-0.08	-0.01
Rosa Linda x Selva	0.00	0.03	-0.00
Sweet Charlie x Camarosa	-0.09	-0.09	-0.09
Sweet Charlie x Cuesta	-0.02	-0.01	0.00
Sweet Charlie x Oso Grande	0.02	0.04	0.04
Sweet Charlie x Selva	0.00	0.00	0.03

Table 26. Continued.

Cross	86 DAP	100 DAP	114 DAP
FL87-236 x Camarosa	0.06	0.05	0.00
FL87-236 x Cuesta	0.06	0.04	0.01
FL87-236 x Oso Grande	-0.06	-0.06	-0.01
FL87-236 x Selva	0.01	-0.01	0.00
FL89-123 x Camarosa	0.01	-0.03	-0.01
FL89-123 x Cuesta	0.08	0.07	0.01
FL89-123 x Oso Grande	-0.02	-0.01	0.00
FL89-123 x Selva	-0.13	-0.08	-0.02
FL90-10 x Camarosa	-0.02	0.03	0.01
FL90-10 x Cuesta	-0.03	-0.02	-0.01
FL90-10 x Oso Grande	0.02	-0.01	0.00
FL90-10 x Selva	0.03	0.00	-0.00
FL92-28 x Camarosa	-0.02	-0.04	0.00
FL92-28 x Cuesta	-0.05	-0.03	-0.00
FL92-28 x Oso Grande	-0.04	0.02	0.00
FL92-28 x Selva	0.04	0.02	-0.00
Rosa Linda x Camarosa	0.02	0.02	0.00
Rosa Linda x Cuesta	0.07	0.05	0.01
Rosa Linda x Oso Grande	-0.02	-0.01	-0.01
Rosa Linda x Selva	0.01	0.02	0.01
Sweet Charlie x Camarosa	-0.04	-0.01	-0.00
Sweet Charlie x Cuesta	-0.02	-0.04	-0.01
Sweet Charlie x Oso Grande	0.06	0.02	0.01
Sweet Charlie x Selva	-0.01	0.02	0.00

Table 27. Estimates of specific combining ability in inflorescence production of strawberry crosses at Dover, Florida (1995-1996).

Cross	January	February
FL87-236 x Camarosa	-0.02	-0.01
FL87-236 x Cuesta	-0.00	0.02
FL87-236 x Oso Grande	0.01	0.02
FL87-236 x Selva	0.01	0.02
FL89-123 x Camarosa	0.01	-0.04
FL89-123 x Cuesta	-0.00	0.01
FL89-123 x Oso Grande	-0.00	-0.01
FL89-123 x Selva	0.00	-0.02
FL90-10 x Camarosa	0.01	0.06
FL90-10 x Cuesta	-0.02	-0.00
FL90-10 x Oso Grande	-0.00	-0.04
FL90-10 x Selva	0.02	0.01
FL92-28 x Camarosa	0.00	-0.02
FL92-28 x Cuesta	0.00	0.02
FL92-28 x Oso Grande	-0.00	-0.02
FL92-28 x Selva	-0.01	0.01
Rosa Linda x Camarosa	-0.00	-0.03
Rosa Linda x Cuesta	0.01	-0.00
Rosa Linda x Oso Grande	0.00	0.04
Rosa Linda x Selva	-0.01	-0.02
Sweet Charlie x Camarosa	-0.00	-0.02
Sweet Charlie x Cuesta	-0.00	-0.01
Sweet Charlie x Oso Grande	0.00	0.00
Sweet Charlie x Selva	-0.00	0.02

Table 28. Estimates of specific combining ability in measures of yield in January of strawberry crosses at Dover, Florida (1995-1996).

Cross	Number of marketable fruit	Marketable fruit weight (g)	Total fruit weight (g)
FL87-236 x Camarosa	-0.10	-2.46	-3.77
FL87-236 x Cuesta	0.00	-0.08	0.14
FL87-236 x Oso Grande	0.03	0.84	1.46
FL87-236 x Selva	0.04	1.09	1.12
FL89-123 x Camarosa	0.02	0.25	1.42
FL89-123 x Cuesta	0.02	0.85	1.17
FL89-123 x Oso Grande	-0.04	-0.19	-1.03
FL89-123 x Selva	0.01	-0.61	-0.77
FL90-10 x Camarosa	0.12	2.41	3.30
FL90-10 x Cuesta	-0.14	-2.76	-4.95
FL90-10 x Oso Grande	-0.20	-0.69	-1.08
FL90-10 x Selva	0.13	2.67	5.52
FL92-28 x Camarosa	0.01	0.12	-0.10
FL92-28 x Cuesta	0.03	0.51	1.06
FL92-28 x Oso Grande	-0.05	-1.05	-1.68
FL92-28 x Selva	-0.06	-0.86	-1.70
Rosa Linda x Camarosa	-0.03	-0.34	-1.09
Rosa Linda x Cuesta	0.05	0.38	0.78
Rosa Linda x Oso Grande	0.06	1.16	2.13
Rosa Linda x Selva	-0.08	-1.13	-1.84
Sweet Charlie x Camarosa	-0.04	-0.41	-0.25
Sweet Charlie x Cuesta	-0.02	-0.20	-0.63
Sweet Charlie x Oso Grande	0.05	0.34	0.79
Sweet Charlie x Selva	0.02	0.16	-0.01

Table 29. Estimates of specific combining ability in average weight (g) of marketable fruit of strawberry crosses at Dover, Florida (1995-1996).

Cross	January	February	March	Season
FL87-236 x Camarosa	0.00	5.23	0.27	0.80
FL87-236 x Cuesta	0.05	-0.45	-0.29	-0.44
FL87-236 x Oso Grande	-0.01	-0.66	0.01	0.24
FL87-236 x Selva	0.06	-0.87	0.28	0.56
FL89-123 x Camarosa	-0.02	-1.18	0.30	0.36
FL89-123 x Cuesta	0.13	0.32	0.68	0.91
FL89-123 x Oso Grande	0.18	-0.35	-0.04	-0.24
FL89-123 x Selva	-0.37	-0.99	-0.16	-0.75
FL90-10 x Camarosa	0.02	-1.40	-0.35	-0.09
FL90-10 x Cuesta	0.04	1.43	0.10	0.06
FL90-10 x Oso Grande	-0.08	0.57	0.16	0.28
FL90-10 x Selva	0.01	-0.95	-0.26	0.10
FL92-28 x Camarosa	-0.05	-1.70	-0.17	-0.48
FL92-28 x Cuesta	0.00	-0.64	-0.17	-0.43
FL92-28 x Oso Grande	-0.05	0.72	0.10	0.12
FL92-28 x Selva	0.18	1.10	-0.13	-0.17
Rosa Linda x Camarosa	0.19	-0.10	0.22	-0.07
Rosa Linda x Cuesta	-0.09	-0.10	-0.03	0.04
Rosa Linda x Oso Grande	-0.06	-0.55	-0.18	-0.20
Rosa Linda x Selva	0.11	0.37	-0.10	0.04
Sweet Charlie x Camarosa	0.03	1.55	0.11	0.28
Sweet Charlie x Cuesta	0.03	-0.10	-0.40	-0.61
Sweet Charlie x Oso Grande	-0.16	-0.06	0.00	-0.14
Sweet Charlie x Selva	-0.14	-1.18	0.08	-0.19

Table 30. Estimates of specific combining ability in fruit firmness of strawberry crosses at Dover, Florida (1995-1996).

Cross	148 DAP	153 DAP
FL87-236 x Camarosa	0.06	-0.12
FL87-236 x Cuesta	0.07	0.04
FL87-236 x Oso Grande	-0.03	0.06
FL87-236 x Selva	-0.14	-0.00
FL89-123 x Camarosa	0.08	0.10
FL89-123 x Cuesta	-0.34*	-0.14
FL89-123 x Oso Grande	0.11	-0.03
FL89-123 x Selva	0.24	0.16
FL90-10 x Camarosa	-0.16	-0.02
FL90-10 x Cuesta	0.13	-0.02
FL90-10 x Oso Grande	-0.07	-0.03
FL90-10 x Selva	-0.06	-0.02
FL92-28 x Camarosa	0.22	-0.01
FL92-28 x Cuesta	-0.18	0.03
FL92-28 x Oso Grande	-0.10	-0.05
FL92-28 x Selva	0.18	0.08
Rosa Linda x Camarosa	0.16	0.09
Rosa Linda x Cuesta	-0.06	-0.03
Rosa Linda x Oso Grande	-0.10	-0.13
Rosa Linda x Selva	0.00	0.06
Sweet Charlie x Camarosa	0.03	-0.02
Sweet Charlie x Cuesta	-0.12	-0.17
Sweet Charlie x Oso Grande	0.28*	0.26**
Sweet Charlie x Selva	-0.23	-0.09

* Significantly different from zero at p=0.05.

** Significantly different from zero at p=0.01.

BIOGRAPHICAL SKETCH

The author was born in Quezon City, Philippines, on June 4, 1963. She grew up in Los Baños, a university town at the foot of Mt. Makiling noted for its lush vegetation and beautiful flowering plants. In this environment, it was not surprising that she developed an extensive interest in horticulture. The author obtained her BS in agriculture and MS in plant breeding at the University of the Philippines in Los Baños.

The author worked at the National Tobacco Administration after finishing her undergraduate degree. She also spent time at the Institute of Plant Breeding and with the Southeast Asia Potato Program for Research and Development. These varied experiences gave her the chance to work on different crops, and with different kinds of people.

In 1993, the author came to the United States to work on her PhD. She is married to Robert C. Kemerait, Jr., a PhD student in the Department of Plant Pathology, University of Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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